POPULATION DYNAMICS OF THE CITRUS SNOW SCALE, *Unaspis citri* (COMSTOCK) (HOMOPTERA: DIASPIDIDAE) AT PARADISE ISLAND, OSCEOLA COUNTY, FLORIDA

By

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To Josefina
With Love

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Abstract of Dissertation Presented to the Graduate Council
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By

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June, 1977

Chairman: Reece I. Sailer
Co-Chairman: Robert F. Brooks
Major Department: Entomology and Nematology

These investigations included the seasonal population dynamics of citrus snow scale, *Unaspis citri* (Comstock), and the effects of *Aspidiotiphagus lounsburyi* (Berlese and Paoli) (Hymenoptera: Aphelinidae) on the citrus snow scale. Parameters included tree age, variety, and location.

The study area was an isolated Central Florida citrus grove located at Paradise Island, Lake Tohopekaliga, Osceola County. The grove occupies approximately half of the 44.52 hectares that comprise the island and is surrounded by native vegetation which includes palm trees, hardwoods, and associated understory.

Periodic counts were made of crawlers, male, and female scales in previously prepared study sites on citrus trunks from August 1975 through January 1977, and of female scales on samples of citrus leaves and twigs from January 1976 through January 1977.

The population curve representing all stages of the citrus snow scale on citrus trunks followed a seasonal pattern: a period of population increase was observed from fall (September-December 1975)

through winter (December-March) and on into spring (March-June 1976) followed by a period of population decline from spring through summer (June-September), and on into fall and winter of 1976-77.

On leaves and twigs, female citrus snow scale generally followed the same trend observed in females on trunks, which peaked in July; however, on both leaves and twigs, there was a secondary peak in November.

Citrus snow scale densities, including all considered stages, increased with tree age on both trunks and leaves. The scale density was also influenced by plant variety. The effect of plant variety could also be detected from scale counts taken from each of the different plant organs. On the trunk the overall population was highest on 'Parson Brown', intermediate on 'Valencia', and lowest on 'Pineapple'. On leaves, 'Parson Brown' had higher female scale density than either 'Valencia' or 'Pineapple', these latter two did not differ significantly in female scale counts.

Aspidiotiphagus parasitism on leaves followed the female scale population trends but it did not show a secondary peak in numbers during November. On twigs, Aspidiotiphagus parasitism was very low and relatively stable during the year.

Precipitation apparently plays an important role in the fluctuations of scale seasonal populations. The onset of daily rainfall in late spring (June) coincides with the period of population decline. Regular scale counts on infested trees and studies of specific colonies in exposed and protected areas on tree limbs suggest that the mechanical washing effect of rainfall and associated runoff contribute to the decline in scale numbers, especially of crawlers and males. The excessive moisture also facilitates growth of microorganisms, some of which may be saprophytic or pathogenic to citrus snow scale.

This study was initially undertaken as a means of obtaining base line data needed to evaluate the result of efforts to colonize the Hong Kong strain of Aphytis lingnanensis Compere (HK-1) on Paradise Island. These efforts failed for unknown reasons. Since HK-1 has successfully controlled citrus snow scale in other locations in Florida, lack of success on Paradise Island might be due to some local peculiarities of climate or other environmental factors.

CHAPTER I

INTRODUCTION

These investigations included the seasonal population dynamics of the citrus snow scale, *Unaspis citri* (Comstock), and the relationship of *Aspidiotiphagus lounsburyi* (Berlese and Paoli) (Hymenoptera: Aphelinidae) to the citrus snow scale. Studies were conducted in an isolated Central Florida citrus grove (Paradise Island). Parameters included tree variety, age, and location in a large grove on relatively high citrus snow scale infestations.

The work is presented in chapters.

A description of the study area, the principal insects, and specifics concerning the commodity plants involved in the study are found in chapter II.

Chapter III summarizes the survey of citrus snow scale infestations on the island. The survey was a preliminary step for 1) describing the area, 2) monitoring citrus snow scale infestations on sweet orange trees, and 3) establishing base line data for population dynamics studies of citrus snow scale and their resident parasites.

Chapter IV deals with citrus snow scale population dynamics. Studies were made by counting crawler, male, and female scales in selected study sites on trunks, from August 1975 through January 1977; studies also included counts of female scales on samples of leaves and twigs from January 1976 through January 1977. In an effort to explain the insects' seasonal fluctuations, direct field observations were made on the effects of rainfall and incident light by 1) covering 2 lower limbs with an artificial plastic and jute roof, 2) wrapping 18 citrus limbs with transparent, blue and white plastic strips, and 3) measuring filtered light in a citrus canopy with a photometer. The first 2 studies were conducted from July through December in 1976, and the third experiment was conducted from December 1975 through September 1976.

Chapter V deals with the attempts to establish and monitor the Hong Kong wasp (HK-1, a strain of *Aphytis lingnanensis* Compere, Hymenoptera: Aphelinidae) at Paradise Island.

Chapter VI contains a summary of conclusions drawn from observations and experiments described in preceding chapters.

CHAPTER II

STUDY AREA, INSECTS, AND CROP PLANTS

Study Area

This study was conducted at Paradise Island, Lake Tohopekaliga, Osceola County, Florida (Fig. 1).

Lake Tohopekaliga has a surface area of about 76 km^2 and drains an area of 1,606 km^2. Its water level stages (between 18.85 and 16.76 m above mean sea level) are controlled and regulated by the Central and Southern Florida Flood Control District (U.S. Army, 1973).

The climate is subtropical. The relative humidity is high the year round (90% at night and 40 to 50% in the afternoon). The annual precipitation ranges from a minimum of 83.82 cm to a maximum of 180.34 cm, with an annual average of 129.54 cm. About 60% of the annual precipitation falls from June through September. Some tropical storms occur in September and October. The average annual temperature is 22.2° C, with a daily maximum of 27.2° C and a daily minimum of 16.7° C (U.S. Dep. Com., 1975; U.S. Army, 1973, 1976).

Paradise Island's center is located $28^\circ 15' 49''$ North and $81^\circ 23' 53''$ West. The studied citrus grove occupies approximately half of the 44.52 hectares that comprise the island; the grove is surrounded by native vegetation which includes palm trees, hardwoods (mainly *Quercus* species) and associated understory. Elevation ranges from 16.76 to 19.81 m above mean sea level. The island is 5 km south of Kissimmee and 20 km south of McCoy Air Force Base; climatological data from these two places are used in this work. Some data on available soil nutrients (calcium, magnesium, phosphorus, and copper) and pH are given in Table 1.

Insects

The Citrus Snow Scale, Unaspis citri (Comstock).

The citrus snow scale belongs to the family Diaspididae (Order Homoptera, Tribe Diaspidini; armored scales). This is the largest family of scale insects and one of the most abundant and damaging groups of arthropods parasitic on perennial crops and ornamental plants (Beardsley and Gonzalez, 1975). Adult female armored scales have two distinctive features: fusion of the two nymphal exuviae with secreted material to form the insect's armor; and the fifth through eighth abdominal segments are fused, forming the pygidium (Ferris, 1942; D'Ascoli, 1971).

The post embryonic development of citrus snow scale is shown in Fig. 2. Citrus snow scale eggs and crawlers are ovoid and yellowish. Once crawlers are settled they turn dark brown. The scale covering of immature males, beginning with the second instar is white, elongate, and tricarinate; it averages 1.16 mm in length. After the second molt, male development resembles that of holometabolous insects since the 3rd and 4th instars are transitional stages between immature and adult winged forms. The scale armor of the female, beginning with the second instar is oyster-shell shaped and usually has a median ridge. The armor is brownish to purplish; its length is 2.41 mm. The adult female is neotenic; although it retains its physical larval characteristics it is sexually mature. Under the armor the female body is elongate and fusiform. The color is pale yellow when immature; at maturity it is bright orange. The body length ranges from 1.80 to 2.25 mm. Females remain apterous and reach sexual maturity in the third instar (Wilson, 1917; Summerville, 1934; Ferris, 1942; Rao, 1949; Merrill, 1953; Pratt, 1958; Dekle, 1965a; Dickens, 1968; Beardsley and Gonzalez, 1975).

The number of generations per year is related to climatic conditions. In Florida, climatic conditions are rarely severe enough to completely prevent reproduction. Bullock and Brooks (1975) report unsynchronized generations and almost continuous presence of crawlers throughout the year. Under field conditions the life cycle has a duration of about 60 days (Brooks, personal communication).

In Queensland (Australia) citrus snow scale breeds continuously throughout the year. The generations overlap and all stages are present at anytime; approximately 5 generations are completed in 12 months. In experimental breedings, females developed in 65 days, and after maturity they produced crawlers from 3 to 6 weeks (Summerville, 1934).

In Japan the arrowhead scale, Unaspis yanonensis (Kuwana), a species related closely to citrus snow scale, has two generations in some places and three in others (Murakami et al., 1974, Tanaka and Inove, 1975).

On 'Valencia' orange fruit (at 25.6 ± 2.2^{o} C, $70 \pm 10\%$ relative humidity, and 12 hours light) Dickens (1968) found that development of adult males from crawlers required a mean of 31.54 days, and adult female development required a mean of 60.2 days. Casares (1974, Table 2) performed a similar experiment with citrus snow scale from Florida cultured on California lemons at four constant temperatures and two fluctuating temperatures in 14 hours light and 10 hours darkness. He found that neither females nor males developed at 12.5° C; female development, from crawler to crawler (F_1) required from 59 days (29.4° C) to 115 days (18.3° C); male development from crawler to adult emergence required 33 days (29.4° C) to 67 days (18.3° C).

On a world basis eighteen natural enemies of citrus snow scale have been reported. These are listed by Casares (1974).

The natural hosts of citrus snow scale belong to the Rutaceae family. The most frequently cited genera are Severina, Fortunella, Murraya, and especially Citrus (Casares, 1974). Earlier records on botanical families other than Rutaceae are dubious (Ferris, 1937); however, there are recent citations on Tillandsia usneoides (Bromeliaceae; "Spanish moss," Tippins and Beshear, 1975).

Colonies of the scale are localized on the trunk, scaffold limbs, and twigs of mature trees; in heavy infestations, colonies also are found on leaves and fruit (Brooks and Thompson, 1963; Bullock and Brooks, 1975).

Economic thresholds for citrus snow scale infestations on citrus have not been established. Citrus snow scales are cited primarily for decreasing tree vigor, the consequences of which include splitting bark, loss of large limbs and foliage, and death of the tree (Pratt, 1958; Brooks and Thompson, 1963; Bullock and Brooks, 1975). According to Talhouk (1975), this insect is a "very important" citrus pest in Australia, Argentina, Venezuela, Colombia, Central America, Mexico, U.S.A., and China; it is an "important" pest in Peru, Chile, and Brazil.

The Hong Kong Wasp, *Aphytis lingnanensis* Compere

The wasp is a member of the family Aphelinidae (Order Hymenoptera). The genus *Aphytis* is common throughout the world and includes many species that are important parasites of armored scales (Rao and DeBach, 1969; Rosen and DeBach, 1973; DeBach, 1974). In Florida, *A. holoxanthus* DeBach and *A. lepidosaphes* Compere were introduced and have successfully controlled the Florida red scale, *Chrysomphalus aonidum* (L.), and the purple scale, *Lepidosaphes beckii* (Newman) (Clancy et al., 1963; Muma and Clancy, 1966; Muma, 1969).

Since some of these parasites are uniparental, sibling and semi-species, detailed biosystematic studies must be carried out in order to establish their identity (DeBach, 1969). Misidentifications in the past have proved very costly. For instance, *Aphytis holoxanthus* and *A. coheni* DeBach were misidentified as *A. lingnanensis*. This delayed man's manipulation of those effective parasites against the Florida red scale and the California red scale, *Aonidiella aurantii* (Mask.), respectively, since true *A. lingnanensis* is ineffective as an enemy of either scale species (DeBach, 1960).

A. lingnanensis is a complex group of sibling and semi-species that cannot be distinguished morphologically. Nonetheless they show differences in host preference, behavior, and other biological aspects that may be used in distinguishing species (DeBach, 1959; Rao and DeBach, 1969; DeBach, 1974).

According to DeBach and Sundby (1963), *A. lingnanensis* is an endoparasitic biparental wasp; females come from fertilized eggs while males arise from unfertilized eggs (arrhenotoky); both adult male and female are yellowish with black areas on the thoracic sterna. Females search for their host mostly at random; usually one egg is deposited per host (the second and third instar female scales). The scale is stung and paralyzed before oviposition occurs. The developmental period in laboratory rearings takes 13 to 14 days on oleander scale, *Aspidiotus hederae* (Vallot), at 27° C; the sex ratio is about 60 females to 40 males on oleander scale and 35 females to 65 males on California red scale. Adult longevity is about 25 days but females may live as long as 40 days with an average of 32 progeny per female. Females require additional proteins from their host for more than minimal egg production. They exhibit a host-feeding behavior that adds significantly to the total host mortality inasmuch as the hosts that are stung and fed upon die as well as those that eventually produce parasites.

The effectiveness of the *A. lingnanensis* complex has some climatic restrictions; in California, for instance, the parasite is better adapted to hotter inland environments. Nonetheless, weather alone does not limit the parasite's range (DeBach and Sisojevic, 1960; DeBach et al., 1971; DeBach, 1974). In Florida, this wasp has been collected from Florida red scale, purple scale, and citrus snow scale in all seasons; however, its incidence is very low and sporadic (Muma and

Selhime, 1966; Muma et al., 1971). Muma and Selhime (1966) suggest that the poor performance of A. lingnanensis in Florida might be explained by the lack of a preferred host. A new Hong Kong strain of A. lingnanensis (HK-1), introduced from the Orient is currently being released in Florida citrus groves against the citrus snow scale (Brooks and Johnson, 1971; Bullock and Brooks, 1975; McCoy et al., 1976; Brooks, 1976). A stock coming from that HK-1 strain was used in part of this research.

The Crop Plants

The plant materials used for this study were sweet orange varieties, Citrus sinensis (L.) Osbeck, Rutaceae.

Presumably many species of Citrus came from subtropical and tropical regions of Asia and the Malay Archipelago (Webber, 1967). Citrus has probably been grown in Florida since 1565 when Saint Augustine was settled by the Spaniards. Today, Florida leads the nation and the world in citrus production (Ziegler and Wolfe, 1975).

Because of several disastrous winter freezes, the center of citrus production in Florida has moved progressively from the northern areas of the state toward the south (Spurlock and Hamilton, 1970).

The amount of foliage growth in Florida citrus groves varies with the season. Fifty-nine percent of the annual growth occurs in the spring with the average peak occurring in mid-March. Additional growth occurs in the summer, peaking at mid-July. A minor flush of new growth occurs in the fall (Simanton, 1970).

The varieties used in this work are 'Valencia', 'Pineapple', 'Parson Brown', and 'Jaffa'. 'Valencia' is a late season variety marketable from late March through June. 'Pineapple' is a midseason variety marketed from January through February. These are the major commercial varieties in Florida. Of the minor varieties, 'Parson Brown' is an early season variety (from October through November). 'Jaffa' is a midseason variety (Ziegler and Wolfe, 1975).

The cultural practices at Paradise Island follow the same pattern of other citrus areas in Florida as described by Ziegler and Wolfe (1975). The only difference between standard practices and the Paradise Island grove was in the chemical control of insect pests; pesticide applications were restricted during the experiments with the HK-1 strain of *Aphytis lingnanensis*. The formulations of pesticides and nutritional sprays applied during 1975 and 1976 are shown in Table 3.

Figure 1. Aerial view of Paradise Island, Lake Tohopekaliga, Osceola County, Florida. The studied citrus grove occupies approximately half of the 44.52 hectares that comprise the island; the grove is surrounded by native vegetation which includes palm trees, hardwoods (mainly *Quercus* species) and associated understory. (Photo is taken from a blueprint of Osceola County Aerial Map No. 34-25-29 reproduced with written permission of the Board of County Commissioners).

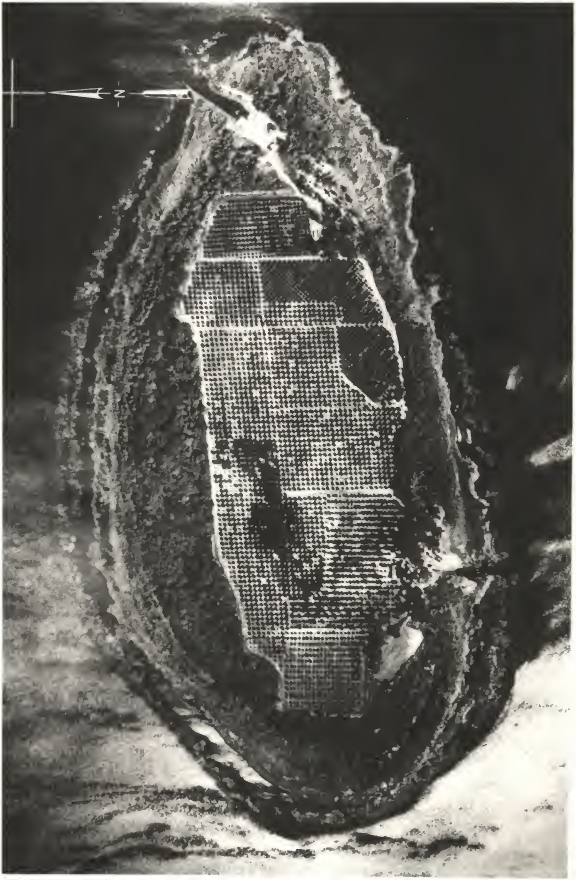
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Figure 2. Postembryonic development of the citrus snow scale, *Unaspis citri*, Homoptera: Diaspididae, in the laboratory on 'Valencia' fruit at 25.6±2.2° C, 70±10 percent relative humidity, and 12 hours light (After Dickens, 1968).

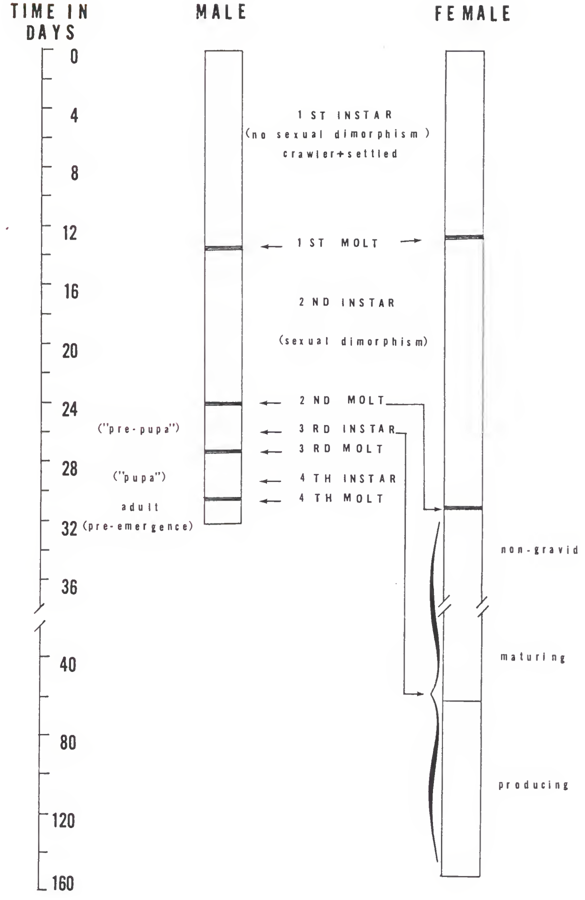

TIME IN DAYS
MALE
FEMALE
0
4
8
12
16
20
24
28
32
36
40
80
120
160
1 ST INSTAR
(no sexual dimorphism)
crawler+settled
1 ST MOLT
2 ND INSTAR
(sexual dimorphism)
2 ND MOLT
("pre-pupa")
3 RD INSTAR
3 RD MOLT
("pupa")
4 TH INSTAR
adult
4 TH MOLT
(pre-emergence)
non-gravid
maturing
producing

Table 1. Available soil nutrients (pounds/acre at depths of 0-15 cm) in 3 sections of Paradise Island citrus grove

Grove Section	Number of Samples	Average of 3 soil analyses for 1975-1976^z				
		pH	Calcium	Magnesium	Phosphorus	Quick Copper
East	3	6.4 (0.50)	2496 (572)	398 (221)	110 (35)	< 50
Central	18	6.7 (0.24)	1609 (391)	213 (54)	72 (24)	93 (52)
West	3	6.6 (0.46)	1872 (134)	406 (22)	67 (36)	50

[z] Mean followed by standard deviation in parenthesis.

Source: Chase Grove Service, Lakeland, Florida.

Table 2. Duration of development of citrus snow scale, *Unaspis citri*, reared on California lemons, *Citrus limon*, under 14-hour light and 10-hour dark at 4 constant temperatures (29.4° C, 23.9° C, 18.3° C, and 12.5° C) and one fluctuating temperature regime (23.9° C in light and 18.3° C in darkness).

From Crawler to:	Duration of Development (Days) at: 29.4° C (705.6)[z]	23.9° C (573.6)	23.9-18.3° C (517.6)	18.3° C (439.2)	12.5° C (300.0)
(a) Females					
1st molt	12.40 a[**]	15.84 b	20.52 c	28.65 d	---[y]
S.D.	1.00	0.63	1.17	1.12	
2nd molt	30.40 a	32.06 b	33.96 c	64.03 d	---
S.D.	1.27	1.90	0.86	0.85	
Crawler (F_1)	59.00 a	60.00 ab	62.90 b	115.33 c	---
S.D.	5.24	1.35	2.02	4.50	
(b) Males					
1st molt	12.50 a	15.97 b	21.19 c	30.25 d	---
S.D.	1.20	0.59	0.86	0.98	
adult emergence	32.80	34.38 b	36.00 c	67.02 d	---
S.D.	1.83	1.62	1.28	0.85	

[z] Hour-degrees per day.

[y] No development. After 68 days at 12.5° C, crawlers were removed to the 29.4° C regime where 70 percent of them developed normally.

[**] Values followed by a different letter within a row are significantly different according to Duncan's new multiple range test at the 1% level.

Source: Casares (1974).

Table 3. Formulations of pesticides and nutritional sprays applied on citrus trees at Paradise Island in 1975 and 1976.

Pesticides and Nutritional Sprays	Materials and Formulations	Rates	Dates	
			1975	1976
Scalicide	Oil no. 435 97%	1%	July 28	July 23-24
Miticide	Chlorobenzilate 4E	2 pts./500	May 13-22	April 9
			July 28	July 23-24
			November 17-18	
Fungicide	Copper oxide 53%	7.5 lbs.		July 23-24
Nutritional spray	Zinc oxide 52%	7.5 lbs.	May 13-22	April 9
	Manganous oxide 48%	5.0 lbs.	May 13-22	

Source: Chase Grove Service, Lakeland, Florida.

CHAPTER III

SURVEY OF CITRUS SNOW SCALE INFESTATIONS ON SWEET ORANGE VARIETIES AT PARADISE ISLAND

Introduction

The primary intent of this investigation was to determine the level of citrus snow scale populations at Paradise Island at the time of the HK-1 Aphytis lingnanensis strain release. In addition it served to establish baseline data for subsequent studies.

Paradise Island presented an opportunity to study the effect of several variables on scale populations. These variables included differences in varieties, tree age, and planting systems.

The need to investigate the effect of different environmental factors on injurious insects and mites in Florida citrus groves has been emphasized by Muma (1970). Through a series of papers, Thompson (1939a, 1939b, 1940, 1941, 1943, 1948), and Griffiths and Thompson (1950), point to the effects of soil nutritional conditions, nutritional sprays, and other cultural practices on scale insect infestations. Several publications concern the effect of plant substances and the nutritional status of the plant on the insect-plant relationship in general (e.g. Painter, 1951; Dethier, 1954; Lipke and Fraenkel 1956; Rodriguez, 1960; House, 1961; van Emden, 1966; Fraenkel, 1969; Singh, 1970; Rodriguez, 1972; Hanover, 1975).

Among Citrus species, mandarins and/or tangerines are notably less susceptible to citrus snow scale than grapefruit, orange, and lemon (Summerville, 1934; Reed et al., 1967; Dickens, 1968). It has also been noted that rough lemon rootstocks, comparing scion and root, show more susceptibility to citrus snow scale than sour orange (Reed et al., 1967). Apparently, no research has been conducted on the susceptibility to citrus snow scale among sweet orange varieties.

Infestation indices are relative estimations of insect abundance. Simanton (1960) compared the seasonal populations of some citrus insects and mites using a 4-class infestation rating. Simanton's classes were: no infestation (0), very light (1), light to moderate infestation (2), and moderate to heavy infestation (3). Reed et al. (1967), evaluated the susceptibility to citrus snow scale among different species of citrus, with a 5-class infestation index, such classes were: no scale visible (0), trace amount (1), light infestation not considered economic (2), moderate infestation of economic importance (3), and a severe infestation (4).

Materials and Methods

During 4 weeks in June 1975, the citrus snow scale infestation on every single orange tree (ca. 3900 trees) on the whole island was rated with a 5-class infestation index. The rating was done along rows, walking around each tree and observing the trunk and main limbs. Only male scales were rated, because their white wax coverings are easily detected on the bark. The key feature checked was the presence of male colonies (both sexes are present, but as it was stated, males are easier to detect than females). These form patches on the bark; larger colonies may encompass the trunk, and heavy infestations may extend from the ground to well up on the main limbs.

The 5 infestation classes, which are diagramed in Figure 3, are:

1. Very heavy infestation. Large colonies of male scale encompassing the trunk and on most of the main limbs.
2. Heavy infestation. Large colonies encompassing the trunk or some of the main limbs. Many patches.
3. Average infestation. Patches are clearly delimited; no large colonies encircling trunks or limbs as in 1 and 2. More than 3 patches on trunks or main limbs.
4. Low infestation. Two or 3 scattered patches.
5. Slight infestation. No colonies or patches. Individual males scattered or absent.

The results of this survey were recorded on maps (Figs. 4-6). Data were tabled with respect to the following variables:

1. Grove sections. On the basis of the citrus snow scale infestation maps, the Paradise Island grove was divided into 3 sections:
    - 1.1. west part of the grove (Fig. 4).
    - 1.2. central part of the grove (Fig. 5).
    - 1.3. east part of the grove (Fig. 6).

The east and west sections of the grove showed a large number of trees in classes 1 and 2 than the central section which had a predominance of class-3 trees.

2. Sweet orange varieties.
    - 2.1. 'Valencia'
    - 2.2. 'Pineapple'
    - 2.3. 'Parson Brown'
    - 2.4. 'Jaffa'
3. Tree planting systems.
    - 3.1. rectangular (square). The spacing between trees is 7.62 m.
    - 3.2. quincunx (a tree is planted in the middle of the square. This gives 78 percent more trees per surface area).
4. Tree age. Age classes were approximated to 5 years.
    - 4.1. less than 10 years old (replants).
    - 4.2. 15-20 years old.
    - 4.3. 25-30 years old.
    - 4.4. 35-40 years old.
    - 4.5. over 45 years old.

For analytical purposes, the 3 grove sections (west, central, and east) were considered blocks. Each section (block) was evenly divided into 16 plots. If the number of trees (same age and variety) per plot was less than 16, each tree was considered a plot (see Pearce, 1976). The mean rating within each plot was based on the number of trees in the plot. Each independent variable (grove section, variety, planting system, and tree age) was considered separately in the analysis, then second order interactions partitioned where data were significant. The arrangement of trees in the field did not allow a balanced survey and, as all the variables were not present in each of the 3 sections, analysis of interactions for some variables was limited.

Results

The survey maps (Figs. 4-6) and means of the citrus snow scale infestation indices (Table 4) show an uneven distribution of the insect infestation in the field during the survey time. In the maps of both west (Fig. 4) and east (Fig. 6) grove sections, scale infestations were generally higher, with a preponderance of trees rated No. 1 and No. 2; in the central section (Fig. 5) there were more trees rated No. 3. Citrus snow scale infestations (Table 4) were heaviest on the western (2.84 mean rating) and eastern (2.89 mean rating) parts of the grove.

Results of the citrus snow scale survey were also analyzed in terms of plant age, plant variety, planting system, and the interaction planting system x variety. They are preliminary results and further evidence should be sought since the survey was not planned to test the effect of those variables on male scale insects. Disregarding other variables, the age of trees has some influence on the scale infestation (Table 5). Trees less than 10 years old and 25 to 30 years old showed less infestation than those 15 to 20 and over 35 years old.

There was a slight difference among varieties (Table 6). 'Pineapple' was more heavily infested than other varieties, with the exception of 'Jaffa' (Table 6). There were no differences between planting systems nor interaction between planting system x variety.

Discussion and Conclusion

The distribution of the citrus snow scale infestation at the time of this survey was not uniform. The infestation maps (Figs. 4-6) show a concentration of citrus snow scale on both east and west sides of the grove.

If the grove sections are compared regarding available soil nutrients (Table 1) and means of citrus snow scale infestation indices (Table 4), the east and west sections have more calcium, more magnesium, less copper (Table 1) and higher citrus snow scale infestation; that is, lower infestation indices (Table 4), than the central section. Calcium and magnesium are needed, among other nutrients, in large quantities by citrus trees (Ben David, 1975). Thompson (1940, and other papers, see introduction) show that purple scale develops faster on well fertilized trees; Muma (1970) found fewer mites on citrus trees deficient in both nitrogen and calcium. If an equal effect of the native vegetation because of its uniform distribution around the grove is assumed it is therefore possible that the high citrus snow scale infestation in those 2 sections (east and west) of the grove has some relation with the nutritional conditions of the soil; however, this is a tentative conclusion since other edaphic factors, such as microbial activity, organic matter, and especially on this island--soil depth, water level fluctuations, and aeration, must also be investigated.

As a group, younger trees were less infested than older trees (Table 5). This is in agreement with Summerville (1934), who observed that young trees were seldom attacked by the scale. We may expect an increasing level of infestation with increased tree age. The group aged 15 to 20 years did not follow this trend (it had a heavy infestation).

Among varieties, 'Pineapple' was slightly more infested than other varieties except 'Jaffa' (Table 6), but 'Jaffa' was not different from 'Parson Brown' and 'Valencia'; thus, it appears that citrus snow scale attacks these varieties with the same intensity. It is also possible that a 5-class infestation index would not be sufficiently sensitive to detect such differences as may have been present. I believe that a 10-class rating index (as is used to rate insect damage in studies on plant resistance to insects) would have yielded more conclusive results.

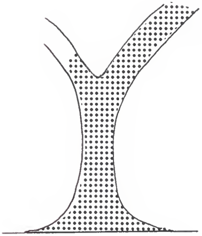
Citrus snow scale infestation appeared not to be influenced by varieties between planting systems.

The survey detected a plant location factor influencing citrus snow scale infestations in the field. Also, it showed some differences among tree-age classes and infestation levels. It failed to detect appreciable responses to male scale infestation among varieties, as well as any cross effect between varieties and planting systems. A 10-class rating index might prove more helpful in this respect. In general, the survey objectives were achieved since data on the working area and materials, necessary for planning future experiments, were obtained.

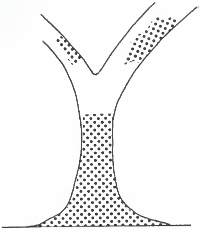
Figure 3. Five-class rating for subjective evaluation of male citrus snow scale, Unaspis citri, infestation on citrus trunks and limbs. The rating key feature was the presence of male colonies.

1. Very heavy infestation. Large colonies of male scales encompassing the trunk and on most of the main limbs.
2. Heavy infestation. Large colonies encompassing the trunk and on most of the main limbs. Many patches.
3. Average infestation. Patches are clearly delimited; no large colonies encircling trunks or limbs as in 1 and 2. More than 3 patches on trunks or main limbs.
4. Low infestation. Two or 3 scattered patches.
5. Slight infestation. No colonies or patches. Individual males scattered or absent.

1



2



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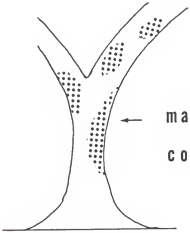
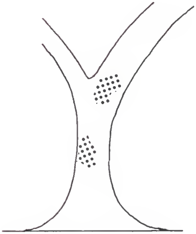


male snow scale colony

4



5

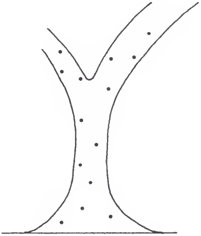


Figure 4. Male citrus snow scale, _Unaspis citri_, infestation map of the western section of Paradise Island citrus grove.

1. Very heavy infestation.
2. Heavy infestation.
3. Average infestation.
4. Low infestation.
5. Slight infestation.

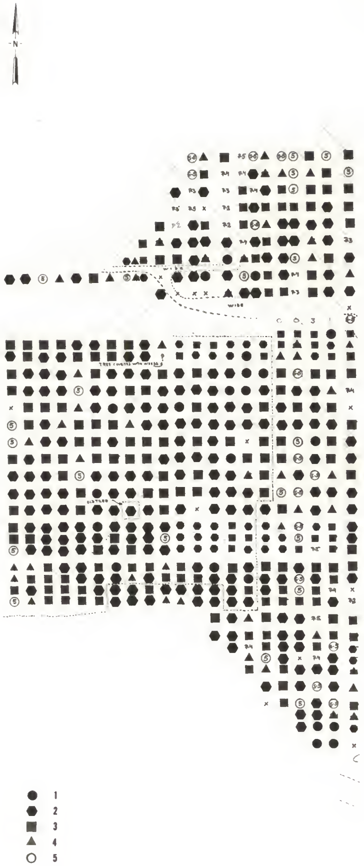

N
WIDE
WIDE
TREE COVERED WITH WEEDS
OLD TREE
● 1
⬢ 2
■ 3
▲ 4
○ 5

Figure 5. Male citrus snow scale, _Unaspis citri_, infestation map of the central section of Paradise Island citrus grove.

1. Very heavy infestation.
2. Heavy infestation.
3. Average infestation.
4. Low infestation.
5. Slight infestation.

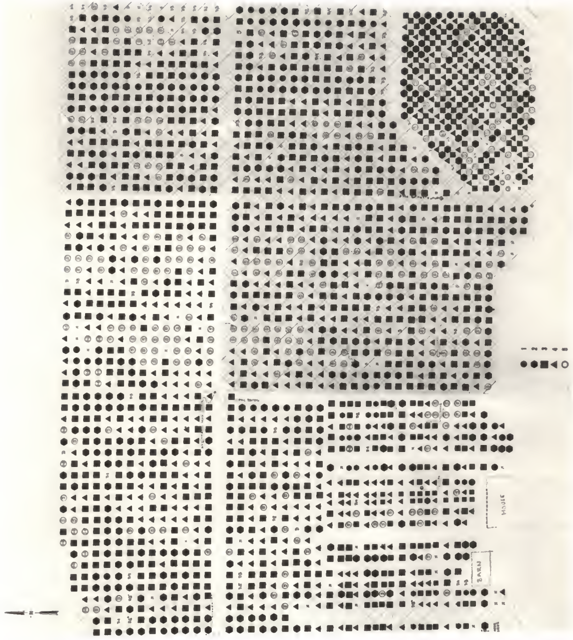

1 2 3 4 5
HOUSE
BARN

Figure 6. Male citrus snow scale, _Unaspis citri_, infestation map of the eastern section of Paradise Island citrus grove.

1. Very heavy infestation.
2. Heavy infestation.
3. Average infestation.
4. Low infestation.
5. Slight infestation.

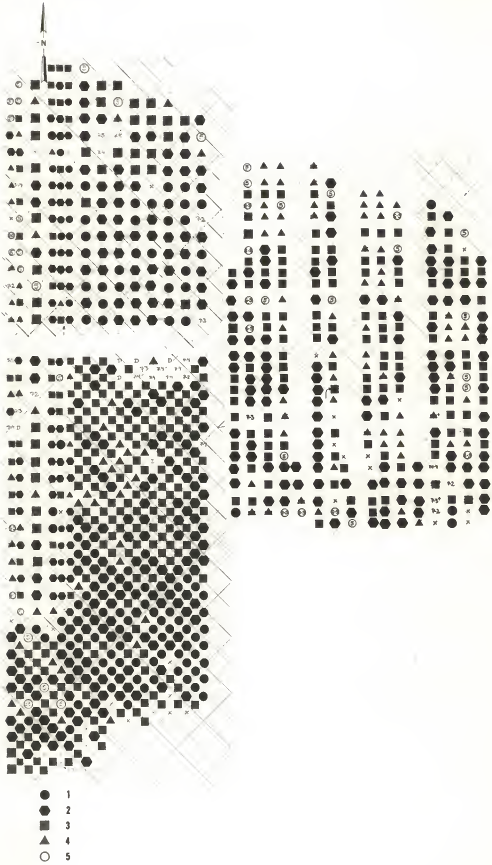

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Table 4. Mean citrus snow scale, Unaspis citri, infestation in June 1975, on 3 sections of Paradise Island citrus grove.

Grove Section	Infestation Index[z]
East	2.89
Central	3.59
West	2.84
L.S.D. 0.05	0.49

[z] Infestation index: 1=very heavy, 2=heavy, 3=average, 4=low, 5=slight.

Table 5. Effect of plant age on citrus snow scale, *Unaspis citri*, infestation in June 1975.

Plant Age (years)[z]	Mean Infestation Index[y]
less than 10	3.71
15-20	2.38
25-30	3.33
35-40	2.92
over 45	2.61
L.S.D. 0.05	0.37

[z] Age classes have an approximation of 5 years.

[y] Infestation index: 1=very heavy, 2=heavy, 3=average, 4=low, 5=slight.

Table 6. Effect of sweet orange varieties on citrus snow scale, *Unaspis citri*, infestation in June 1975.

Plant Variety	Mean Infestation Index^{z}
'Pineapple'	2.77
'Jaffa'	3.00
'Parson Brown'	3.23
'Valencia'	3.37
L.S.D. 0.05	0.39

[z] Infestation index: 1=very heavy, 2=heavy, 3=average, 4=low, 5=slight.

CHAPTER IV

CITRUS SNOW SCALE POPULATION DYNAMICS

Introduction

This experiment studied citrus snow scale population dynamics, to evaluate some of the biotic and abiotic factors that could be involved in scale population fluctuations, and to compare the data gathered at Paradise Island with those reported for other North-Central areas of Florida. Also it was anticipated that data on population dynamics would be used for evaluating the effectiveness of Hong Kong 1 (HK-1), a strain of *Aphytis lingnanensis* (see Biological Control Experiments, Chapter V), by comparing citrus snow scale population data at Paradise Island before and after HK-1 release with data from HK-1 free areas of North-Central Florida.

Population changes in insects with overlapping generations (e.g. the citrus snow scale) are hard to detect and describe, not only because the data required are extensive and laborious to obtain but also because they are difficult to interpret (Varley and Gradwell, 1970; Varley et al., 1974). Citrus snow scale is present in Florida year around (Bullock and Brooks, 1975). R. F. Brooks and coworkers at the Agricultural Research and Education Center, Lake Alfred (University of Florida, Institute of Food and Agricultural Sciences) have recorded populations of the citrus snow scale in different Florida citrus production areas. Some of their unpublished data on citrus snow scale on sweet orange leaves are shown in Figures 7 and 8. Figure 7 is a summary of data concerning only female citrus snow scale in groves near Umatilla, Oviedo, Clermont, and Howey-in-the-Hills (northern portion of the citrus belt); in Figure 8 the data are summarized again with respect to female scales on leaves for groves near Polk City, Davenport, Auburndale, and Lake Alfred (Central Florida). In Figure 7, a peak in female population on leaves of sweet orange trees occurred in May 1972. In 1973 the peak population period was extended in duration with particularly high levels of female scales in February and May. The lowest population levels were observed in July 1972, and October-November 1973. In Figure 8, representing data from Central Florida, peaks in female population on leaves occurred in April of both 1972 and 1973. The minimum female populations occurred in August 1972, and December 1973.

In this study the scale population was monitored on different plant organs: trunks, twigs, and leaves. On trunks, scale crawlers and males and females were counted at 8-week intervals from August 1975 to January 1977. On twigs and leaves only female scales (this is the sex parasitized by HK-1) were counted at 8-week intervals from January 1976 to January 1977; their parasitism by Aspidiotiphagus lounsburyi was also recorded.

The citrus snow scale infestation survey (Chapter III) showed the Paradise Island citrus grove exhibited 2 levels of scale abundance. The central section had low to average scale infestations ($\overline{x}$=3.59, Fig. 5, Table 4), while the west and east sections had average to heavy infestations ($\overline{x}$=2.84 and 2.89, respectively; Figs. 4 and 6, Table 4). In this population dynamics study, an attempt was made to determine seasonal population trends by sampling these 2 areas. Qualitative and quantitative data were taken on the scale insect habitat including preferred places for colony establishment, interaction with microbes, algae and parasites, and the effects of rainfall and light.

These investigations were patterned after Summerville's (1934) extensive work on citrus scale insects in Queensland (Australia). Although no quantitative data were shown, he observed that temperature did not affect citrus snow scale to a considerable extent, although humidity seemed important for scale development. He also found that the insects were more noticeable in dry than in wet seasons, and were more abundant on older trees than on young replacement stock.

In a review of habitat manipulation in Florida citrus, Muma (1970) reiterated the possible importance of microhabitat characteristics in the survival and reproduction of citrus pests including citrus snow scale. Observations made first in 1885 by Hubbard in the U.S.A. suggested that shaded citrus groves harbored larger armored scale populations than unshaded ones. Although cultural habits have changed considerably since that time, i.e. groves are now planted in full sun as opposed to being planted in shady oak-palm hammocks, there apparently are some shade effects that are great enough to be documented in microhabitat collections of other citrus pests such as citrus rust mite (Muma, 1970). Although data are not presented specifically on citrus snow scale populations in different shading conditions, the previous observations on armored scale infestations and microhabitat preferences of rust mites are conducive to hypothesizing that citrus snow scale colonies may preferentially develop in the shadier areas on tree trunks.

Of the other microhabitat elements mentioned by Summerville (op. cit.), the effects of both temperature and relative humidity extremes would tend to be moderated by the comparatively large lake surrounding Paradise Island (temperature, particularly, is moderated by large water reservoirs, MacArthur, 1972). However, there are seasonal differences in rainfall and this factor seemed worthy of further study as it might relate to microhabitat fluctuations of citrus snow scale populations at Paradise Island.

In 1975 the mechanical effect of heavy and persistent rainfall was suspected to have an adverse influence on scale colonies. It seemed that water draining from the limbs as well as the direct action of rain could dislodge and remove the scale. Also, it seemed that citrus snow scale colonies were very noticeable under some of the colored strips used to tag experimental trees. Further, there appeared to be an inverse relationship between green algae and scales. That is, where scale populations were readily apparent, algae were absent. Conversely where algae were present, citrus snow scale colonies were sparse or absent. One possibility is that the scales could not compete with the algae and were thus excluded from bark locations otherwise suitable for colonization. Alternatively, with a change in microclimatic conditions, perhaps relating to rainfall, the growth of algae was promoted while the vigor of scale colonies declined.

Manpower was one of the major limitations of this work. During winter and spring of 1976 most of the researcher's time was diverted to the study of HK-1 parasitism (see Biological Control Experiments, Chapter V), so one observation on population dynamics scheduled for that period was skipped.

Materials and Methods

Population Dynamics

Citrus trunks. Individual trees (experimental plots) for monitoring the scale population fluctuations on citrus trunks were selected on the basis of tree age, variety, and grove section. The age classes 15-20, 25-30, and 35-40 years were identified on the grove map (these classes were unevenly distributed in the field, Table 7). Blocks of the major varieties, 'Valencia' and 'Pineapple', were selected on the map in such a way that both varieties were present in the east or west and central grove sections (Table 7). 'Parson Brown' was present only in the central grove section. Thus, 5 sites were selected in the grove to study population dynamics. These areas were 2 'Pineapple' blocks (one in the west and another in the east grove sections), 2 'Valencia' blocks (one in the central and another in the east grove sections) and 1 'Parson Brown' block (in the central grove section). A number was assigned to each row and column of the selected area. One tree per area (Table 7) was selected from each site for monitoring scale populations; the tree was selected at random using Fisher and Yates' table of random numbers (1963). If the selected tree was either diseased or close to the border of the study site, that tree was eliminated from these particular observations; diseased trees were generally in poor physical conditions and some were near death. Border trees were not considered in the study because some trees, by chance, could be on the periphery of the grove adjacent to wild shrubs and trees. The effects of these wild plants on citrus snow scale populations were not to be considered in this study. By eliminating trees along the other border lines of the study site, the possibility of observing immediately adjacent trees in 2 different study sites was eliminated. Also excluded from the study were those trees classified as number 1 or 5 according to the infestation index (Fig. 3; see Materials and Methods, Chapter III).

On each of the 5 selected trees, a colony of scale insects was chosen. Four areas located in the center of the colony were cleaned of scales by brushing them off with a toothbrush; an aluminum template was used to delimit uniform square (2 x 2 cm) areas. Care was taken to avoid scratching the bark surface. Square location was determined by ease of access since subsequent observations were made with a hand-lens. Location of squares on trunks, tree variety, age classes, planting system, and grove sections are shown in Table 7.

Square counts were made at 8-week intervals (as practiced by the staff at the Research Center) but between winter 1975-76, and spring 1976 one count was skipped because of conflicting biocontrol experiments (Chapter V) and the schedule subsequently had to be rearranged. The planned schedule was August, October, and December 1975; February, April, June, August, October, and December 1976. The rearranged schedule was August, October 1975; January, April, July, September, November 1976; and January 1977.

In June 1975 the 20 squares were located and cleaned. The first examination was made on 13 August 1975; after each examination the square was brushed again. At each observation, citrus snow scale stages were counted. The insect stages recorded and the counting procedure follows:

1. Settled and moving crawlers were counted and removed with a dissection needle.
2. Empty male wax coverings, and parasitized males were removed.
3. Crawlers were again counted and removed.
4. Live males were counted and removed.
5. Crawlers were again counted and removed.
6. Females were counted and removed. Compared to males, females are hard to notice because their wax covering color resembles that of the bark. Slightly scratching the bark assisted in removing the female covering, the orange or yellow female body is then easily detected.
7. A final count on crawlers was made.
8. The square was brushed clean. A final hand-lens examination was made for remaining stages.

The process is time consuming (5 to 15 minutes per square), but other methods such as infrared photography of study squares have not proved superior (Terry, 1976).

To explain the variations in counts of crawler, male, and female scales as well as total adult and total of all stages a second order linear model was fitted using the following classification variables: grove section, date, variety, age, and planting system. These terms were entered as first order variables. Second order interactions were partitioned where data were significant.

Leaves and twigs. The monitoring tree and 2 neighboring trees were sampled in each of the 5 study areas. Three samples (at least 20 leaves and one 5-cm long twig per sample) were picked from each study plot. Since infested leaves and twigs are more likely to be found inside the canopy, in close proximity to well infested branches, samples were taken only from this restricted universe.

Leaves and twigs were examined in the laboratory under a stereoscopic binocular microscope (13.5 x magnification). Only female scales were counted and examined for parasites. This procedure was followed in anticipation of documenting dispersal of HK-1 which would ordinarily parasitize only female scales. Female scales were counted as either non-gravid (2nd instar and non-gravid 3rd instar) or as gravid (adult gravid). By observation and rearing Aspidiotiphagus was recorded in 2nd and 3rd instar females although it also parasitizes male scales.

Leaves and twigs were sampled from January 1976 through January 1977, at the same time the squares were studied.

Data were analyzed by fitting a second order linear model to the data. The following first order classification variables were used: grove section, date, variety, age, and planting system. Second order interactions were partitioned where data were significant.

Rainfall

Direct field observations on rainfall effects were made from June through December in both 1975 and 1976. Development of microorganisms, especially lichens and algae were observed on tree limbs. It was suspected that the mechanical effect of heavy and persistent rainfall not only washed insects off the bark, but also promoted the growth of microorganisms in wet colonies, and the development of algae on suitable places for citrus snow scale. In July 1976 this possibility was examined on 2 algae-covered limbs on the same tree by protecting them against the direct impact of rainfall and sunlight with a roof, and tying colored plastic strips snugly around other algae-covered limbs in different grove sections.

The protective covering was a sack (48 x 33 cm) made of plastic and jute. It was horizontally placed at about 15 cm above the tree limb. These protected areas were observed until December 1976. Qualitative observations were made on citrus snow scale crawler activity, presence of live males and females, and the development of microorganisms, algae, and lichens.

Three 2.5 cm-wide plastic strips, colorless, blue, and white (1 color = 1 treatment), were spaced at 10 cm intervals and were fastened around two different limbs (= replications).

The transparent strips allowed light penetration, while the blue and white ones restricted it to various extents. Although 18 limbs on 9 trees (2 limbs per tree) were included in the original study, the strips on 14 of the limbs either fell off or were destroyed during the experimental period between July and the end of December 1976.

To evaluate this experiment, strips were removed and the presence of either citrus snow scale or algae was noted. Since the color and translucence of the white and blue strips were not quantified, data from these 2 treatments were grouped; hereafter, this new classification was called colored strips. Three 2 x 2 contingency tables were constructed using data from the transparent and colored strips treatments. These tables were used with Fisher's exact probability test (2-tailed) to statistically test whether citrus snow scale or green algae was associated with the strip types. They were also used to test any association between citrus snow scale and green algae.

Light Experiments

A 75 cm^2 citrus snow scale colony was located on the south side of a nearly vertical citrus limb. On this limb 6 sites were marked and identified as "south colony," "south above," "south below," "north," "east," and "west." The three sites on the south were located at 180° N; the south colony was at the middle of the citrus snow scale colony and south above and south below were 10 cm above and below the south colony, respectively. North (20° N), east (100° N), and west (270°N) were at the same level (130 cm) as the south colony. The placement of the sites on the limb, the inclination of each site from the vertical plane and the observation schedule are illustrated in Figure 9.

At each site the incident light was measured in lux with a Lambda$^{(R)}$ photometric sensor (Inst. Corp. PH 279-7502) coupled to a Li-Cor$^{(R)}$ Ll-170 Quantum/Radiometer/Photometer. This particular sensor detects wave lengths of light generally used by plants in photosynthesis. The direct incident sunlight was recorded and transformed into percent of incident light by the formula: percent incident light = (incident light at each site/direct sunlight) x 100.

Readings were made at 1-minute intervals when the sun was highest in the sky; the first reading was the incident sunlight, followed by readings at the 6 sites on the limb. Total observation time lasted approximately 1½ hours. It was assumed that the sunlight regime was uniform during readings; however, passing clouds caused some extreme shading. When this happened and readings differed by more than 25 percent of the base line data, the reading process was temporarily suspended. A recent but unavailable electronic development, an electronic integrator, would avoid some of these inconveniences by simultaneously measuring the sunlight and the light penetration in the canopy at any location. The latter is a direct reading of percent light penetration (King, 1974).

Originally I planned to take light measurements very close to the winter solstice (21 or 22 December), the vernal equinox (20 or 21 March), the summer solstice (21 or 22 June), and the autumnal equinox (22 or 23 September); however, the actual schedule was modified for personal convenience to include 23 December 1975, 31 March, 18 June, and 7 September 1976 (Fig. 9).

One limitation of these data is that only 1 scale colony was observed in a single tree. However, 10 replications were made of each reading on each observation date at all 6 study sites on the limb. The observation dates were purposely selected to coincide with those critical days of the year, the equinoxes and solstices, when day lengths were changing or at the extremes of their increasing and decreasing cycles. Analysis of variance on the incident light data was done using dates, light readings, and site x date interactions.

Results

Population Dynamics

Citrus trunks. The fluctuations in populations of crawlers (both moving and settled), and male and female citrus snow scales are shown in Figure 10 along with summary data for all stages. The total population curve shows a decline from August through October 1975 (summer-fall) where a population minimum occurred (21 scales, all stages, per cm^2). From October 1975 through January 1976 (fall-winter) there was a slight population increase (approximately 10 percent); from January through April (winter-spring) a marked population increase occurred (383 percent), peaking in April with more than 90 scales (all stages) per cm^2. After April the total population curve declined approximately 22 percent from April through July (spring-summer); from July through September (summer) the decline was precipitous with populations decreasing from approximately 72 scales (all stages) per cm^2 to 21 scales per cm^2. The decline continued from September through November 1976 and on into January 1977. When observations ceased, the total scale density was approximately 1 per cm^2. This was the lowest population level observed during this study.

Crawlers (both moving and settled), and male citrus snow scales peaked at approximately the same time, April 1976 (Fig. 10), but the seasonal minimum for crawlers occurred from October 1975 through January 1976, while the seasonal minimum for males was restricted to

October 1975. Female citrus snow scale peaked in July 1976 and reached a seasonal low level in January 1976 (Fig. 10).

Considering only age of trees (Table 8), the overall mean of citrus snow scale density (total population, all stages) increased with tree age, from 42.72 scales per 4 cm^2 in the 15-20 year age class up to 201.33 scales in the 35-40 year age class. The highest crawler, male, and total scale densities were also observed on trees in the oldest age class. The fewest males, females, total adult, and crawlers were counted on trees in the 15-20 year age bracket. Within each age class, except for the 15-20 year category, the number of crawlers was at least 60% larger than the next most numerous group, male scales. Male scales, in turn, were at least twice as abundant as female scales with the highest male: female ratio (approximately 7:1) occurring in the 35-40 year age class.

Considering only the factor plant variety (Table 9), 'Parson Brown' harbored the highest overall mean scale density (265.25 scales, all stages, per 4 cm^2). Mean scale density on 'Valencia' was 145.67 scales, all stages, per 4 cm^2. 'Pineapple' harbored fewest citrus snow scales (98.75 scales, all stages, per 4 cm^2, Table 9). No appreciable differences occurred among varieties with respect to female density (Table 9); the mean values observed for the 3 varieties ranged from 2.63 to 12.69. The mean population densities observed for male total adult and crawler stages were significantly different for these 3 varieties. 'Parson Brown' trees had the highest male scale density (85.06 scales per 4 cm^2 bark). 'Valencia' had an intermediate number of male scale present (48.59 scales per 4 cm^2 bark) but this value was significantly higher than that observed for 'Pineapple' (32.46 scales per 4 cm^2 bark). The same ranking of varieties, from highest to lowest scale densities was also observed for total adult scale and for crawler populations (Table 9).

Citrus leaves. On leaves female citrus snow scales peaked in July (Fig. 11a, 4.5 non-parasitized females per leaf) with a lower, secondary peak in November 1976 (3.3 non-parasitized females per leaf). The lowest population of non-parasitized female scales occurred in January 1977 (approximately 1 non-parasitized female per leaf).

Parasitism by Aspidiotiphagus in only female scales on leaves (Fig. 11 b) increased from January 1976 (winter) to July (summer) where the peak, 5 parasitized females per leaf occurred; a decline in parasitism continued until January 1977 when less than 1 female per leaf was parasitized. Parasitism in citrus snow scale 3rd instar was always less than 1 per leaf. Parasitism in female 2nd instar reached more than 4 per leaf in July, 2 in September, and 1 in November; all other values were less than 1 parasitized scale per leaf.

With respect to citrus snow scale population dynamics on leaves (Table 10), the density of female scales increased with host age. There were 1.33 total females per leaf in the 15-20 year age class, 2.71 in the 25-30 year age class, and 3.35 in the 35-40 year age class. The number of females per leaf was significantly lower in the youngest age class than in the other 2 age groups; however, the difference in scale densities in the latter were not significant.

Levels of Aspidiotiphagus parasitism were significantly different only in the youngest (15-20 years) and oldest (35-40 years) age bracket; higher variability in levels of parasitism was observed in the 25-30 year age class.

With respect to plant variety (Table 11), 'Parson Brown' harbored the highest total female scale density (5.65 non-parasitized female per leaf). No significant differences were found between 'Valencia' and 'Pineapple'; they had 2.08 and 2.13 non-parasitized females per leaf, respectively (Table 11). Aspidiotiphagus parasitism in female citrus snow scales followed the same trends as female scale densities on leaves of the 3 varieties. Total parasitism on 'Parson Brown' amounted to 4.95 female scales per leaf; on 'Valencia' the value was 1.08, and on 'Pineapple' 1.06. These last 2 varieties did not differ significantly with respect to levels of Aspidiotiphagus parasitism.

Citrus twigs. The seasonal counts of citrus snow scale females on twigs (Fig. 11c) followed the same trends observed on citrus leaves (Fig. 11 a). Female scale densities reached a peak in July 1976 (4.2 non-parasitized females per cm^2 of twig with a lower, secondary peak in November 1976 (3.1 non-parasitized females per cm^2 of twig). The lowest population of non-parasitized female scales occurred in January 1977, approximately 2.3 non-parasitized females per cm^2 of twig (Fig. 11 c). Aspidiotiphagus parasitism in female citrus snow scale on twigs (Fig. 11 d), did not show significant variation during the study; Aspidiotiphagus never parasitized more than 0.5 female scales per cm^2 of twigs.

Neither female scale populations nor Aspidiotiphagus parasitism on twigs showed significant differences among tree ages or among sweet orange varieties.

Rainfall

One direct effect of rainfall was the physical removal of moving crawlers and males of citrus snow scales from the bark owing to the impact of the water droplets or the draining water on limbs.

The major indirect effect of rainfall observed on citrus snow scales was the development of microorganisms on the soaked insect colonies. Green algae grew on those wet areas receiving additional light.

Citrus snow scale colonies developed on those areas of algae-covered citrus limbs that were protected with an artificial roof (Fig. 12), contrasting with unprotected areas where no scale colonies were established. On covered areas also, green algae partially disappeared from sites of previous establishment, and the development of other microorganisms was reduced.

Results from some of the transparent and colored plastic strip treatments around limbs are shown on Tables 12 and 13. Citrus snow scales were present under 5 out of 8 colored strips, and they were absent under all 4 transparent strips (Table 12); the P=0.0707 (2-tailed Fisher's exact probability) indicates that strip type (transparent vs colored) and citrus snow scale response are associated. Green algae were present under 3 out of 4 transparent strips, and they were absent under all 8 colored strips (Table 13); the P = 0.0181 (2-tailed Fisher's exact probability) indicates that strip type and green algae are associated. There was no association between algae and citrus snow scale (Table 14).

Light Experiments

On the first reading date, 23 December 1975, the colony site (south colony, Table 15) received an intermediate amount of light (18.82 percent incident light) when compared to the other 2 south sites; south above had 20.34 while south below had 13.45 percent incident light. The south colony reading was the same as that obtained for the east site (18.82 percent incident light); these values were greater than those measured from the west (10.08) and north (15.63) sites.

On 31 March, the light reading for all sites were considerably lower than values obtained earlier. The 3 south sites received the most light, overall, followed in order by the east, north, and west.

Readings for all 6 sites were lower still on 18 June 1976. The south above site had the highest incident light value (1.75 percent); values obtained for the other 2 south sites were considerably lower (1.13 for south colony and 1.21 for south below) than 1.75 percent and were lower than measurements made at either the east (1.42 percent) or west (1.29 percent). The least light was received by the north site.

Light readings increased again on 7 September and were comparable in magnitude to those reported for 31 March. In September, south colony received the highest amount of incident light (3.49 percent), followed in order by the east (2.22), south below (1.83), south above (1.23), north (1.70), and west (1.67).

Discussion and Conclusion

The population curve representing all stages of the citrus snow scale on citrus trunks (Fig. 10) at Paradise Island on Lake Tohopekaliga (Osceola County, Florida), followed a seasonal pattern: a period of population increase was observed from fall (September-December 1975) through winter (December-March) and on into spring (March-June 1976) followed by a period of population decline from spring through summer (June-September), and on into fall and winter of 1976-77. The same general trends were observed not only for total citrus snow scale population but also with slight variations, for crawlers, males, and females. Crawler and male scale populations peaked in April, while female scales reached a maximum density in July. All scale stages showed low population levels in January 1977, but in January 1976 only females reached the seasonal minimum during that month. In October 1975, both crawlers and males declined to a low population level. Thus, it seems possible that natural factors responsible of regulating citrus snow scale populations have differential effects on both sexes and the different developmental scale stages; these effects are in turn reflected in the overall scale population dynamics.

On leaves and twigs female citrus snow scale generally followed the same trend observed in females on trunks; however, on both leaves and twigs, there was a secondary peak in the female population in November (Fig. 11 a and c). This suggests that female citrus snow scale population dynamics are distinctly influenced by the different plant organs on which the scales may occur. This variation in scale density responses on different plant organs have been reported for other scale species (Kozar, 1976).

Considering tree age, citrus snow scale densities (all stages considered) increased with tree age on both trunks (Table 8) and leaves (Table 10). Levels on these 2 organs were quite different, however, with leaves supporting only a small fraction of the scales harbored on trunks. For example, female scale counts on leaves (Table 10) indicated that an average of 1.33 females per leaf were on trees 15-20 years of age, 2.71 females per leaf on 25-30 year trees and 3.35 females per leaf on 35-40 year old trees. Female scale counts for comparable surface areas on trunks (actually, leaf area is greater) in the same tree age classes (Table 8) indicated that the corresponding numbers of females for each age class tested above were 5.94, 15.09, and 9.84, respectively.

The tree age did not significantly affect the scale density on twigs. However, the sample of twigs probably was too small (1 twig per subsample, 3 twigs per each of the 5 study areas) resulting in large variances of scale counts in each area. This precluded the detection of significant differences, even though the sample mean showed some trends (Fig. 11, c and d).

The variety factor also influenced the scale population with respect to not only total scales (all stages) but also particular stages. The effect of variety could also be detected from scale counts taken from the different plant organs. For instance, on trunks, the overall population was highest on 'Parson Brown', intermediate on 'Valencia', and lowest on 'Pineapple' (Table 9); female scale densities did not follow the same trend, however. 'Valencia' had the most females per unit of bark while 'Pineapple' had the least; the counts from 'Parson Brown' placed that variety intermediate between 'Valencia' and 'Pineapple' although the variation observed in counts for this variety obscured any significant differences. Considering female scales on leaves, 'Parson Brown' had higher scale density on leaves than either 'Valencia' or 'Pineapple'; these 2 latter did not differ significantly in female scale counts.

The scale counts on bark did not correlate well with subjective evaluations on these three varieties based a 5-class infestation rating index (Chapter III). In the rating index 'Pineapple' had the highest male infestation (Table 6); this value was significantly higher than that observed for either 'Parson Brown' or 'Valencia'.

We cannot compare survey data (Chapter III) with population dynamics data because: 1) the survey was a subjective evaluation while population dynamics studies were quantitative data, 2) differences in time; the survey was carried out in June 1975, whereas population dynamics covered a period from August 1975 through January 1977, 3) differences in population cycles; the survey was done at a period of citrus snow scale population decline, whereas population dynamics covered all population cycles (increase, stable, and decrease), 4) it is suspected, as mentioned in Chapter III, that a 5 point index system may not be sensitive enough to detect subtle differences among varieties.

Our results have shown the different effects of various factors on particular citrus snow scale stages or on the whole scale population. These results suggest that not only different evaluation methods but also, scale stages, plant organs, and other factors (economic, ecologic, etc.) must be combined to get a reliable understanding of the citrus snow scale status.

Aspidiotiphagus parasitism was studied only in female citrus snow scale on leaves and twigs, even though these parasites also attack male scales. On leaves, Aspidiotiphagus followed the female scale population trends but did not show a secondary peak in numbers during November (Fig. 11 b). Female second instars were the preferred hosts. On twigs Aspidiotiphagus parasitism was very low and relatively stable during the year (Fig. 11 d). This parasite has been cited as a generally ineffective citrus snow scale parasite because it lacks host specificity (Muma et al., 1971); however, since 2 alternative hosts for Aspidiotiphagus in Florida [purple scale, Lepidosaphes beckii (Newman) and Florida red scale, Chrysomphalus aonidum (L.)] have been nearly eliminated by other introduced parasite species, at least at Paradise Island, Aspidiotiphagus may play a slightly more important role in the regulation of citrus snow scales. Unfortunately, the parasite seems to be most active (50 percent of female hosts parasitized) and most abundant on leaves, an organ where scales are less abundant than on twigs. Aspidiotiphagus has its largest host population available in in the summer (July) when scale populations reach a seasonal peak.

Aspidiotiphagus parasitism followed the same trends as female scale populations with respect to the variables of plant age and variety (Tables 10 and 11). Like their female hosts, Aspidiotiphagus were significantly more abundant on leaves of 'Parson Brown' than on either 'Valencia' or 'Pineapple'. Aspidiotiphagus and their female host on leaves were most abundant on trees in the 35-40 year class with a trend toward lower populations on 25-30 year old trees and still lower on trees in the 15-20 year age class.

Results of observations and preliminary experiments on the effect of precipitation on citrus snow scale indicate that precipitation could play an important role in the regulation of the scale populations. The literature indicates the detrimental effect of rainfall on other scale species (Beardsley and Gonzalez, 1975). In Figures 7, 8, and 10, the periods of scale population decline (spring-fall) coincide with periods of high rainfall. Field observations suggested that scales (males and crawlers) were removed by the physical impact of water droplets and the washing effect of drainage water through insect colonies. Indirectly, water promoted the development of microorganisms that were detrimental to scale insect survival.

During rainy periods, scale colonies developed on limbs artificially protected from direct rainfall and light (Fig. 12). Scales were present under colored plastic strips that protected the insects from direct rainfall and light (Table 12). In the field, scale colonies tend to survive throughout the year if they are located on well protected areas of the host trees such as the under sides of limbs. Scale colonies in sunny, more exposed areas on tree trunks or limbs appeared to be more prone to the disruptive physical effects of rainfall.

If one imagined an orange tree as a solid cube, one would expect less light to fall on the north side of the cube in the northern hemisphere. Light exposure would probably be most intense and prolonged on the south side of a solid object. Insolation on the eastern side of this generalized solid would occur primarily in the morning hours whereas the western side would receive light principally in the afternoon and evening. When the sun is highest in the sky, one would expect incident light to strike the east, south, and west simultaneously, but perhaps be slightly stronger on the south side where rays would be more direct.

In the natural situation studied here the orange tree canopy was not a geometric cube but more closely resembled a sphere with projecting branches and leaves irregularly shading the central trunk.

During the light experiment readings obtained from the south generally were higher than those recorded for the other sites. The outcome of the experiment was directly affected by the pattern of tree growth and the rate of leaf and twig production during the different seasonal flushes.

Initially, a reproductively active citrus snow scale colony was located at the south site on the study tree. According to the previously reported experiment involving colored and transparent plastic strips, citrus snow scale colonies flourished where light was comparatively dim (under colored strips) and did not flourish where light was brighter (under the transparent strips, Table 12). Consequently, during the course of the light experiment, the citrus snow scale colony was expected to spread to areas where light was dimmer and perhaps be replaced by algae during the rainy season. Instead, the citrus snow scale colony was reproductively active through the 31 March reading but declined after that and completely disappeared by the 9 September observation. Perhaps the decline and disappearance of the colony were due to heavy rainfall although supporting data were not available. No other scale colonies appeared on the study tree either in the shadier areas or in different parts of the south side. Consequently, the relationship between compass readings on a tree and the amount of incident light is more complicated than originally supposed; similarly the association between incident light and citrus snow scale colony establishment is obscure and probably is dependent on a series of subtle interacting microenvironmental factors; nonetheless, the effect of light on citrus snow scale warrants further investigations since in other scale insects, a photophase-temperature relationship has been proved, both in laboratory and field conditions, to be responsible for crawler production (Willard, 1972). If a similar relationship is found on citrus snow scale, this in addition to other factors would help us to understand the onset of the scale populations.

Figure 7. Female citrus snow scale, *Unaspis citri*, population fluctuations on sweet orange leaves in the northern portion of the citrus belt (Umatilla, Oviedo, Clermont, and Howey-in-the-Hills); and the rainfall for the area (After Brooks, unpublished data; U. S. Department of Commerce).

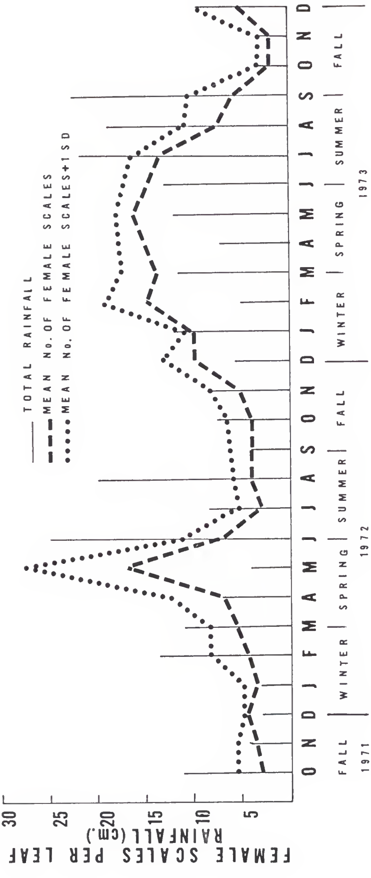

TOTAL RAINFALL
MEAN No. OF FEMALE SCALES
MEAN No. OF FEMALE SCALES+1 SD
FEMALE SCALES PER LEAF
RAINFALL (cm.)
30
25
20
15
10
5
O N D J F M A M J J A S O N D J F M A M J J A S O N D
FALL
WINTER
SPRING
SUMMER
FALL
WINTER
SPRING
SUMMER
FALL
1971
1972
1973

Figure 8. Female citrus snow scale, *Unaspis citri*, population fluctuations on sweet orange leaves in Central Florida (Polk City, Davenport, Auburndale, and Lake Alfred); and the rainfall for the area (after Brooks, unpublished data, U.S. Department of Commerce).

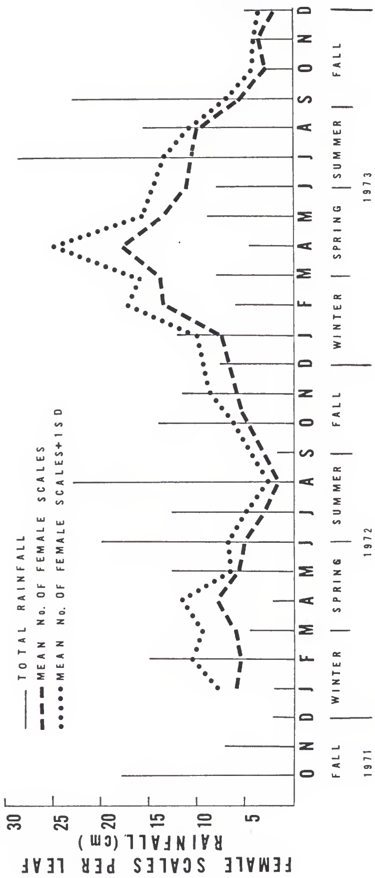
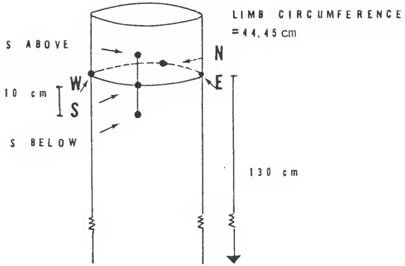

FEMALE SCALES PER LEAF
RAINFALL (cm)
30
25
20
15
10
5
TOTAL RAINFALL
MEAN No. OF FEMALE SCALES
MEAN No. OF FEMALE SCALES+1 SD
O N D J F M A M J J A S O N D J F M A M J J A S O N D
FALL
WINTER
SPRING
SUMMER
FALL
WINTER
SPRING
SUMMER
FALL
1971
1972
1973

Figure 9. Some details of a light experiment conducted in a citrus tree canopy. Observation schedule, site inclination from vertical plane (=0), and orientation by compass reading of 6 study sites for measurements of incident light on a nearly vertical citrus tree limb. The south colony site was at the middle of a citrus snow scale, *Unaspis citri*, colony.



Site		
Identification	Orientation	Inclination
South colony	180° N	-12
South above	180° N	+ 2
South below	180° N	-16
West	270° N	-24
North	20° N	+16
East	100° N	+14

Reading Schedule

23 December 1975
31 March 1976
18 June 1976
7 September 1976

Figure 10. Citrus snow scale, *Unaspis citri*, seasonal fluctuations on citrus trunks at Paradise Island and the rainfall for the area in the same time period.

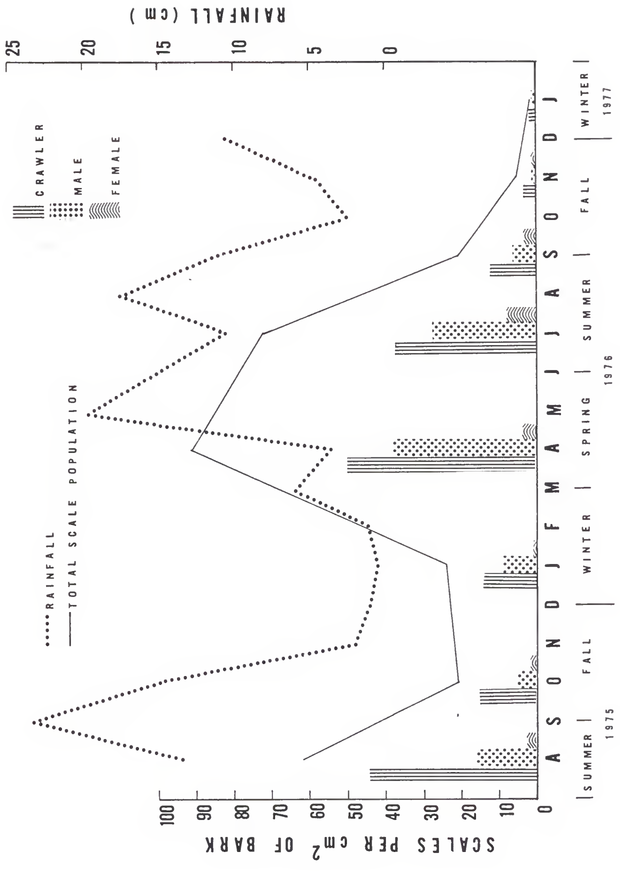

RAINFALL
TOTAL SCALE POPULATION
CRAWLER
MALE
FEMALE
RAINFALL (cm)
25
20
15
10
5
0
SCALES PER cm² OF BARK
100
90
80
70
60
50
40
30
20
10
0
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
SUMMER
FALL
WINTER
SPRING
SUMMER
FALL
WINTER
1975
1976
1977

Figure 11. Population curve of non-parasitized female citrus snow scale, *Unaspis citri*, on leaves (a) and twigs (c). Female scale parasitism by *Aspidiotiphagus lounsburyi* on leaves (b) and twigs (d).

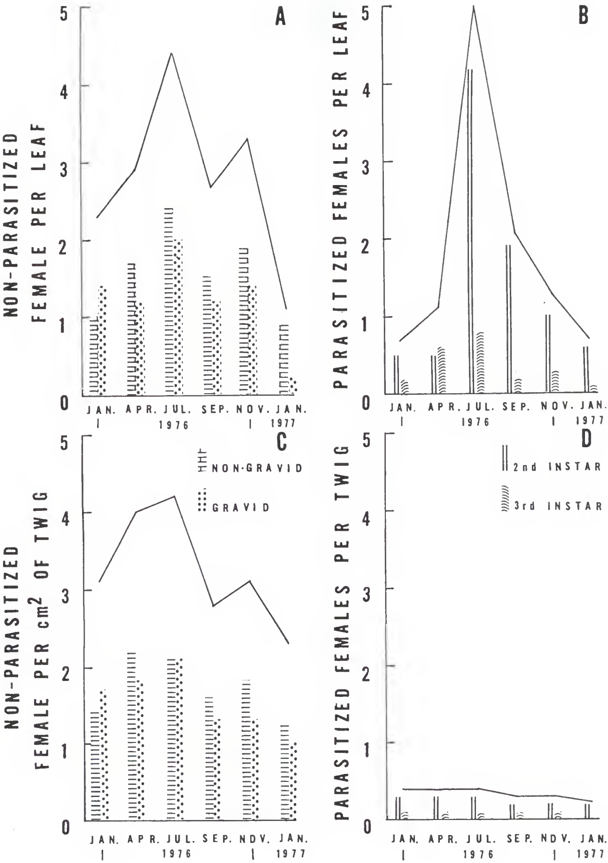

A
NON-PARASITIZED FEMALE PER LEAF
B
PARASITIZED FEMALES PER LEAF
C
NON-GRAVID
GRAVID
NON-PARASITIZED FEMALE PER cm2 OF TWIG
D
2nd INSTAR
3rd INSTAR
PARASITIZED FEMALES PER TWIG
0
1
2
3
4
5
JAN.
APR.
JUL.
SEP.
NOV.
NDV.
JAN.
1976
1977

Figure 12. An artificial roof partially protecting a citrus limb against the direct impact of rainfall and sunlight. Above, both protected and unprotected areas are covered with algae and no citrus snow scale, Unaspis citri, colonies are present (July 1976). Below, unprotected areas remain as above, but on the protected area some algae disappeared and a well-developed insect colony was established (November 1976).

Table 7. Some characteristics of sweet orange trees and selected study sites on their trunks (4 uniform square areas each measuring 2.00 x 2.00 cm, and located in the middle of a citrus snow scale, *Unaspis citri*, colony) in which crawler, male, and female citrus snow scale were counted at 8-week intervals from August 1975 through January 1977 at Paradise Island.

Grove Section	Tree			Location of Squares on Trunks		
	Variety	Age Class (years)	Planting System^z	Height from Ground Level (cm)	Vertical Inclination (degrees)^y	Orientation
West	'Pineapple'	15-20	rectangular	152.40	-10	280° N
	'Valencia'	25-30	rectangular	93.98	-16	355° N
Central	'Parson Brown'	35-40	rectangular	86.36	- 6	15° N
	'Pineapple'	35-40	quincunx	88.9	- 4	50° N
East	'Valencia'	35-40	rectangular	111.76	-34	15° N

[z] Average spacing between trees in the rectangular system is 7.62 m. The quincunx system has one tree in the middle of the planted rectangle.

[y] Minus (-) squares are facing the ground at the given degrees of inclination.

Table 8. Influence of plant age on numbers of different stages of citrus snow scale, *Unaspis citri*, on citrus trunks.

	No. Insects per 4 cm^2 of Bark[z]				
Plant Age (years)	Crawler	Male	Female	Total Adult	Total Population
15-20	19.85	16.94	5.94	22.88	42.73
25-30	58.47	35.56	15.09	50.65	109.12
35-40	123.05	68.44	9.84	78.28	201.33
L.S.D. 0.05	3.07	4.63	3.24	3.41	3.07

[z] Means of observations taken at 8-week intervals from August 1975 through January 1977.

Table 9. Influence of plant variety on numbers of different stages of citrus snow scale, Unaspis citri, on citrus trunks at Paradise Island.

Plant Variety	No. Insects per 4 cm^2 of Bark[z]				
	Crawler	Male	Female	Total Adult	Total Population
'Parson Brown'	170.31	85.06	9.88	94.94	265.25
'Valencia'	84.39	48.59	12.69	61.28	145.67
'Pineapple'	54.19	37.78	7.66	45.44	99.64
L.S.D. 0.05	3.07	4.63	3.24	3.41	3.07

[z] Means of observations taken at 8-week intervals from August 1975 through January 1977.

Table 10. Influence of plant age on numbers of female citrus snow scale, *Unaspis citri*, on citrus leaves and parasitism by *Aspidiotiphagus lounsburyi*.

Plant Age (years)	No. Females per Leaf[z]			No. *Aspidiotiphagus* per Leaf		
	Non-Gravid	Gravid	Total	In 2nd instar CSS	In 3rd instar CSS	Total
15-20	0.74	0.59	1.33	0.72	0.28	1.00
25-30	1.61	1.10	2.71	1.20	0.37	1.57
35-40	1.80	1.55	3.35	1.77	0.44	2.21
L.S.D. 0.05	0.42	0.55	0.83	0.70	0.14	0.65

[z] Means of observations taken at 8-week intervals from January 1976 through January 1977.

Table 11. Influence of plant variety on numbers of female citrus snow scale, *Unaspis citri*, on citrus leaves and parasitism by *Aspidiotiphagus lounsburyi*.

Plant Variety	No. Females per Leaf[z]			No. *Aspidiotiphagus* per Leaf		
	Non-Gravid	Gravid	Total	In 2nd instar CSS	In 3rd instar CSS	Total
'Parson Brown'	3.35	2.30	5.65	4.02	0.93	4.95
'Valencia'	1.11	0.97	2.08	0.80	0.28	1.08
'Pineapple'	1.09	1.04	2.13	0.82	0.24	1.06
L.S.D. 0.05	0.42	0.55	0.83	0.70	0.14	0.65

[z] Means of observations taken at 8-week intervals from January 1976 through January 1977.

Table 12. Two-way contingency table (2 x 2) showing observed and expected frequencies obtained from a trial on the subjective evaluation of the presence or absence of citrus snow scale, *Unaspis citri*, underneath transparent or colored plastic strips 5 months (July-December 1976) after strips were tied around algae-covered citrus limbs.

Citrus snow scale response	Treatments and Response Frequency[z] Transparent Strips Observed	Expected	Colored Strips[y] Observed	Expected	Total Observed
Present	0	(1.67)	5	(3.33)	5
Absent	4	(2.33)	3	(4.67)	7
Total	4	(4.00)	8	(8.00)	12

[z] P = 0.0707 calculated for the Fisher's exact probability test (2-tailed).

[y] Colored strips include observations collected under both blue and white strips.

Table 13. Contingency table (2 x 2) showing observed and expected frequencies obtained from a trial on the subjective evaluation of the presence or absence of green algae underneath transparent and colored plastic strips 5 months (July-December 1976) after strips were tied around algae-covered citrus limbs.

	Treatments and Response Frequency[z]				
	Transparent Strips		Colored Strips[y]		Total
Algae Response	Observed	Expected	Observed	Expected	Observed
Present	3	(1)	0	(2)	3
Absent	1	(3)	8	(6)	9
Total	4	(4)	8	(8)	12

[z] P - 0.0181 calculated for the Fisher's exact probability test (2-tailed).

[y] Colored strips include observations collected under both blue and white strips.

Table 14. Two-way contingency table showing the relationship between green algae and citrus snow scale responses regarding the presence or absence of these organisms underneath transparent or colored plastic strips 5 months (July-December 1976) after strips were tied around algae-covered citrus limbs.

		Green Algae Response Frequency^z				
		Present		Absent		Total
		Observed	Expected	Observed	Expected	Observed
Citrus snow scale	Present	0	(1.25)	5	(3.75)	5
Response frequency	Absent	3	(1.75)	4	(5.25)	7
	Total	3	(3.00)	9	(9.00)	12

^{z} P = 0.1591 calculated for the Fisher's exact probability test (2-tailed).

Table 15. Percent of incident light on 6 sites located on a vertical citrus limb (14.5 cm diameter); the south colony site was at the middle of a citrus snow scale, *Unaspis citri*, colony.

Site						
Identification	South Colony	South Above	South Below	West	North	East
Location	180° N	180° N	180° N	270° N	20° N	100° N
Inclination degrees^{z}	-12	+2	-16	-24	+16	+14
Date			Percent Incident Light^{z}			
23 December 1975	18.82	20.34	13.45	10.08	15.63	18.82
31 March 1976	2.94	4.35	3.04	1.81	2.07	2.47
18 June 1976	1.13	1.75	1.21	1.29	0.88	1.42
7 September 1976	3.49	1.73	1.83	1.67	1.70	2.22

L.S.D. 0.05 = 1.26

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[z] Inclination in degrees from vertical plane. South colony, west, north, and east sites were at 130 cm above ground level, and south above and south below were 10 cm above and below the south colony, respectively.

CHAPTER V

BIOLOGICAL CONTROL EXPERIMENTS

Introduction

Even before 1850, Florida citriculturists had arthropod pest problems. As grove acreage increased, and new cultural practices were adopted, there was an accompanying increase in the number and severity of insect pest problems, especially those caused by scale insects (Thompson, 1939a, 1939b, 1940, 1941, 1943, 1948; Griffiths and Thompson, 1950). Since most of these pests were accidentally introduced from other citrus producing countries, their efficient natural enemies or "counterpests" (Sailer, 1961) were lacking.

Classical biological control has been successful in this state. Cottony-cushion scale (*Icerya purchasi* Maskell), purple scale, and Florida red scale were controlled by natural enemies imported into the United States from other countries (Clancy et al., 1963; Muma and Selhime, 1966; Muma, 1969). However, the complete control of Florida red scale and purple scale by 1963 marked the advent of citrus snow scale as an injurious pest. Its presence and potential importance in several citrus production areas has been discussed by several authors (Brooks and Thompson, 1963; Brooks, 1964; Brooks et al., 1972; Brooks and Johnson, 1973; Dekle, 1965b; Reed et al., 1967; Simanton, 1972; Johnson et al., 1972; Johnson and Brooks, 1974). Today, the citrus snow scale is exceeded in importance only by greasy spot disease, *Mycosphaerella citri* Whiteside, and the citrus rust mite, *Phyllocoptruta oleivora* (Ashm.) (Bullock and Brooks, 1975). Biological control must be considered a component of the total insect pest control structure (Sailer, 1972). This is the case with greasy spot disease, citrus rust mite,and citrus snow scale in the University of Florida's pest management program for arthropods and diseases in citrus agroecosystems (McCoy et al., 1976).

As with most armored scales, citrus snow scale is an eurymerous insect since it can thrive on different organs of the host plant (Beardsley and Gonzalez, 1975). However, Kozar (1976), has pointed out that such plant organs may be attacked with different degrees of intensity.

For sampling considerations it is useful to know the citrus snow scale distribution in the canopy. The knowledge of those restricted universes where the scale is found facilitates the stratification of samples and increases the precision of calculated means needed to establish changes and trends in population numbers (Southwood, 1966; Wadley, 1967). Scale infested leaves as well as twigs are more likely to be found inside the canopy, in close proximity to well infested branches.

There have been no effective parasites of citrus snow scale in Florida. Two *Aspidiotiphagus* species are also found on citrus snow scales; they also attack many scale species both males and female second instars (Muma et al., 1971). Previous surveys of scale parasites in Florida suggest that neither species is an abundant or effective scale parasite. In 1961 Aphytis lingnanensis was found in Florida on citrus snow scale and other scale insects, but its incidence in all hosts was very low and sporadic (Muma and Selhime, 1966).

Currently, the Hong Kong 1 strain of Aphytis lingnanensis (HK-1) is being released in Florida at different citrus growing localities and seasons, in accordance with usual procedures for natural enemy colonization (van den Bosch and Messenger, 1973). If an effective parasite against citrus snow scale is found, it would be a major success, not only in Florida but also in those developing countries where the scale is a serious pest (DeBach, 1971).

As originally planned, this study was to be primarily concerned with the dispersion patterns and the effectiveness of HK-1 against citrus snow scale at Paradise Island, an isolated place with areas of heavy citrus snow scale infestation and where no previous releases of HK-1 had been made. In the present study innoculative releases of HK-1 were to be followed by systematic sampling of leaves and twigs for evaluation of citrus snow scale parasitism.

Patterns of insect dispersion from a fixed site can be established by tracking the insect along two fixed lines or directions, for instance north-south, and east-west (Dobzhansky and Wright, 1943; Allen and Gonzalez, 1974). Periodic sampling along these transects should then reveal any changes as these relate to movement of a population through time and space.

Evaluation of a parasite's effectiveness is both a complicated and controversial matter (DeBach and Huffaker, 1971; DeBach, 1974). Comparisons of host population densities, before and after the controlling agent is released, have frequently been used as a measure of the parasite effectiveness (Bess and Haramota, 1956; Selhime et al., 1969; DeBach and Huffaker, 1971; Frazer and van den Bosch, 1973). Other techniques are the use of life tables, key factor analyses, enemy exclusion, and enemy interference or repression (DeBach and Huffaker, 1971; van den Bosch and Messenger, 1973; Tamaki, 1973; DeBach, 1974).

Materials and Methods

In May 1975 a survey was conducted in the area to evaluate natural parasitism of citrus snow scale prior to release of the HK-1 strain of *Aphytis lingnanensis*. Wasp stocks were supplied by the Citrus Experiment Station at Lake Alfred. In their insectary the parasite is reared on ivy scale, *Aspidiotus hederae* (Vallot), colonized on potato tubers. The rearing conditions are 22.5° C and 60% relative humidity.

Adult parasites were supplied in plastic containers (5 cm diameter, 11 cm high). These were placed in a polystyrene box for transportation to the field. Since the Experiment Station is close to the working area (ca. 56 km), parasites were not refrigerated during transport.

In the field, the release site was a tree heavily infested with citrus snow scale. It was located in the central grove section in a 'Valencia' block of 25-30 year old trees. The tree was enclosed by a cage (3.65 m x 3.65 m x 3.65 m), built and described by Brooks and Vitelli (1976) who reported that it facilitated parasite establishment.

The cage consists of a light and sturdy tubular frame and a screen cover (52 x 52 mesh/inch). The parasites were released by manually emptying them from the plastic containers onto the tree. A week later the tree cage was removed.

About 10,000 parasites were released each time on four different dates: 15 May 1975 (late spring), 21 August 1975 (late summer), 6 January 1976 (early winter), and 5 March 1976 (late winter). In January, half of the parasites were released outside the tree cage; in March they were released by directly placing the lab-infested potato tubers at the release site without the tree cage. Normal emergence of parasites from those potatoes was verified by direct field observation.

The sampling process was started three weeks after the parasite release. The first set of samples were taken from 4 sites. Each site was 3 trees removed (about 30 m) from the release point. Two sites were along the rows, N and S of the release site, and two were located perpendicularly across the rows, i.e., E and W of the release site. At 3-week intervals sample sites were progressively advanced in each direction by 3 trees (30 m, Fig. 13). At each site the designated tree and the four neighboring trees were sampled, thus making 5 samples per site. Only the sites scheduled to be sampled on a given date were studied. When no evidence of HK-1 was found at any of the sites the next scheduled samples were taken from the release tree. Each sample consisted of one small twig (5 cm long) of at least 20 leaves picked at random, in groups of 3 to 5, from a given infested stratum of the canopy. This stratum contained infested leaves and twigs in close proximity to well infected branches.

Once the sample was completed, it was placed in a plastic bag in an iced cooler for transportation and later studies in the laboratory at either Lake Alfred or Gainesville. In the laboratory the samples were examined under a stereoscopic binocular microscope (13.5 x magnification). Since HK-1 parasitized only female scales counts of healthy and parasitized scales were restricted to this sex; no counts or notes on parasitism were made for crawlers (less 2nd instar), males or other scale species. Female citrus snow scales were counted and recorded as either non-gravid or gravid. Aspidiotiphagus parasitized female scales were counted and recorded; parasite identifications were confirmed by rearing the wasps from affected 2nd and 3rd instar females.

Results

At the time of the pre-released survey (May 1975) approximately 74.66 percent of a sampled adult citrus snow scale population were males and 25.34 percent were females. These data provided a sex ratio of 1 male:0.34 females. The survey made prior the HK-1 release gave no indication of Aphytis species on citrus snow scale at that time (May 1975). The only parasite found was Aspidiotiphagus sp. and it occurred in both male and female scales. In post-release surveys, samples were held for emergency of parasites and in isolated rearings only Aspidiotiphagus lounsburyi (Berlese and Paoli), Hymenoptera: Aphelinidae, was recovered. This species emerged only from 2nd instars scales.

No HK-1 were recovered from either of the two releases made in

1975 (15 May and 21 August); 20 samples were taken in the release area following the previously mentioned sampling regime (Fig. 13). In August 1975, many adult parasites were trapped in spider webs on the release tree. To reduce this cause of mortality the spiders and webbing were partially removed by hand on this same date.

On the 6 January 1976 release date, there were no spiders on the release tree. When released, the parasites were observed actively searching for hosts. On 20 January the first set of samples was taken. No parasites were found at the 4 scheduled sampled sites, but parasitized scales were found on the release tree. Here they were present only on scales on twigs; HK-1 parasitism was estimated at 6 percent (n = 436). This was the 1st record of HK-1 at Paradise Island. In the 2nd and 3rd sets of samples (each sample consisting of 20 subsamples there was no evidence of HK-1 presence on any of the trees.

In the 5 March 1976 release, the parasites were also very active. On 31 March (26 days after HK-1 release) some HK-1 were recovered both north and west of the release site but they parasitized less than 5 percent of female snow scale on leaves and twigs; more parasites were reared from leaves than twigs (Table 16). The parasites showed a slight dispersal movement toward the north and west. This may indicate the influence of prevailing wind direction provided that the Orlando jetport's data on wind direction (Table 20) are also valid for Paradise Island.

On 21 April (47 days after HK-1 release) HK-1 was recovered only on the north (Table 17), parasitizing about 19 percent of the scales on leaves, and 14 percent on twigs.

On 14 May (70 days after HK-1 release) only a few parasites (less than 1 percent) were recovered on the north, south, east, and west of the release site (Table 18). At this time there was a remarkable increase in parasitism by Aspidiotiphagus on leaves reaching a maximum of 64.58 percent on the north, a minimum of 12.50 percent on the south and a mean of 37.52±21.32 percent for the 4 sampled areas.

Because of the decline in parasitism by HK-1 the release site was sampled again on 28 May (84 days after HK-1 release). Less than 7 percent parasitism by HK-1 was found, with 4.84 percent of the HK-1 being dead pupae (Table 19). The presence of Aspidiotiphagus was high at this time as well (58.46 percent on leaves).

Subsequent samples on the area gave no evidence of live HK-1; only dead HK-1 pupae were found.

Discussion and Conclusion

Results of the survey on citrus snow scale parasites, prior to the HK-1 release at Paradise Island (May 1975) agree with those reported by Muma and Selhime (1966), and Muma (1969). These authors found that the incidence of Aphytis lingnanensis (Florida strain) was very low and sporadic.

The sex ratio found in the field scale population (1 male:0.34 female) is very close to 1:0.37, reported by Casares (1974) under experimental fluctuating temperatures (23.9° C in light and 18.3° C in darkness). This suggests that fluctuating temperatures are more appropriate for citrus snow scale laboratory studies. The species' high allocation of energy for male production should be investigated further.

The excess of males may relate to multivoltinism; and unsynchronized emergence and maturation of the sexes; however, field observations indicated that males are more vulnerable than females to unfavorable environmental conditions. The effects of higher male mortality would tend to be offset by the greater number of males produced.

The reason for the HK-1 failure was not clear. Obviously, the abundance of spider webs present at the time of the August 1975 release was detrimental to parasite survival. Other workers have noted the adverse effects of such webbing on parasites (DeBach, 1974).

After the 6 January 1976 release, HK-1 was not recovered at places other than the release site. It could be inferred that the HK-1 stock did not adequately disperse at that time. However, after a release on 5 March 1976 the parasite was collected 30 m north and at 30 m west of the release site (Table 16); in subsequent samples, parasites were recovered 60 m north (Table 17), and 90 m north, south, east, and west of the release site (Table 18). At this time HK-1 parasitism was very low, from 0.32 percent on twigs in the east to 2.08 percent on leaves in the north. This decline in parasitism was also found at the release site on 28 May 1976, where parasitism was only 1.85 percent on leaves and 0.60 percent on twigs. Samples taken weeks later contained no HK-1 parasitized scale. The 5 March release was the most successful because the parasite survived in the area for at least 84 days.

While the HK-1 strain of Aphytis lingnanensis was not established at Paradise Island during these studies, the recoveries and low level of parasitism observed following the January and March 1976 releases indicate that prospects for establishment are best when stocks are released during the cooler months of the year.

Finally, a more intensive inquiry should be made into the problems relating to successful HK-1 colonization at different places and times of years.

Figure 13. Sampling scheme for female citrus snow scale, *Unaspis citri*, on citrus leaves and twigs after the Hong Kong 1, a strain of *Aphytis lingnanensis*, was released at Paradise Island.

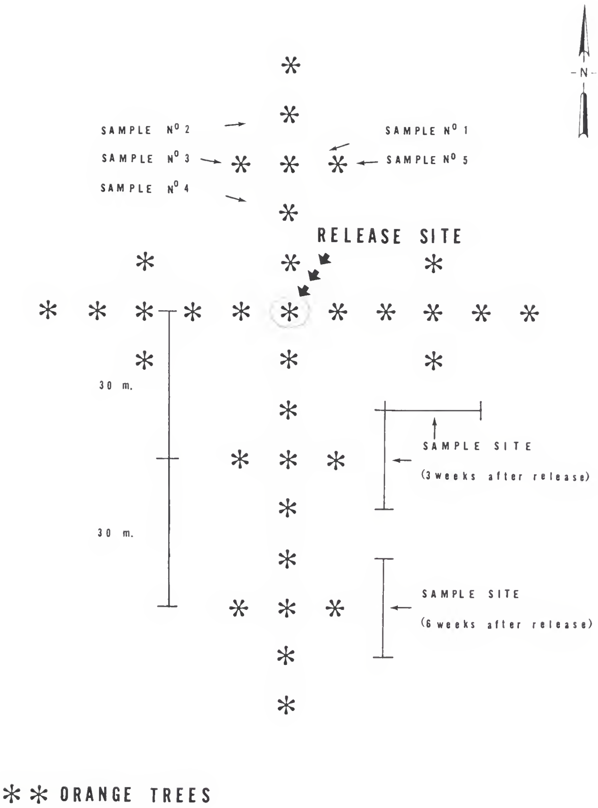
N
SAMPLE N° 2
SAMPLE N° 1
SAMPLE N° 3
SAMPLE N° 5
SAMPLE N° 4
RELEASE SITE
30 m.
SAMPLE SITE
(3 weeks after release)
30 m.
SAMPLE SITE
(6 weeks after release)
✱ ✱ ORANGE TREES

Table 16. Percent of female citrus snow scale (CSS), *Unaspis citri*, non-parasitized and parasitized by HK-1 and *Aspidiotiphagus lounsburyi* on 31 March 1976 (26 days after HK-1 release) at about 30 m north and 30 m west of the release site. No HK-1 was recovered in the south or east.

Plant Organ	Total No. Females CSS Examined	Non-Parasitized		Parasitized[z]			
				HK-1 on 3rd instar CSS		*Aspidiotiphagus* In	
		Non-Gravid %	Gravid %	Total Live %	Dead Pupa %	2nd instar CSS %	3rd instar CSS %
				NORTH			
leaves	286	47.59	29.76	3.16	1.00	14.71	3.80
twigs	223	41.47	45.53	0.34	0	6.63	6.03
				WEST			
leaves	194	52.53	25.25	4.04	0	15.16	3.03
twigs	268	42.27	43.30	1.03	0	6.19	7.22

[z] HK-1 = *Aphytis lingnanensis* Hong Kong 1.

Table 17. Percent of female citrus snow scale (CSS), Unaspis citri, parasitized by HK-1 on 21 April 1976 (47 days after HK-1 release) at about 60 m north of the release site. No HK-1 was recovered in the south, east, or west.

Plant Organ	Total No. Female CSS Examined	HK-1 on 3rd instar CSS			
		Eggs %	Larvae %	Pupae	
				Live %	Dead %
leaves	236	0.54	2.51	7.80	8.18
twigs	642	0	3.43	7.32	3.58

[z] HK-1 = Aphytis lingnanensis Hong Kong 1.

Table 18. Percent of female citrus snow scale (CSS), *Unaspis citri*, non-parasitized and parasitized by HK-1 and *Aspidiotiphagus lounsburyi* on 14 May 1976 (70 days after HK-1 release) at about 90 m north, 90 m south, 90 m east, and 90 m west of the release site.

Plant Organ	Total No. Females CSS Examined	Non-Parasitized		Parasitized[z]					
				HK-1 on 3rd instar CSS				*Aspidiotiphagus* In	
		Non-Gravid %	Gravid %	Egg %	Larva %	Pupa Live %	Pupa Dead %	2nd instar CSS %	3rd instar CSS %
					NORTH				
leaves	96	20.83	10.42	0	2.08	0	0	64.58	2.08
twigs	353	45.33	42.48	0	0	0	0.28	9.06	2.83
					SOUTH				
leaves	136	39.71	33.02	0	0.74	0.74	0	12.50	13.24
twigs	168	41.67	43.45	0	0	0	0	1.19	13.69
					EAST				
leaves	66	33.33	16.67	0	0	0	1.51	37.89	10.61
twigs	309	45.31	42.07	0	0.32	0	0	9.71	2.59
					WEST				
leaves	225	47.56	12.89	0	0.44	0	0	35.11	4.00
twigs	89	44.94	40.45	0	0	0	0	11.24	3.37

[z] HK-1 = *Aphytis lingnanensis* Hong Kong 1.

Table 19. Percent of female citrus snow scale (CSS), *Unaspis citri*, non-parasitized and parasitized by HK-1 and *Aspidiotiphagus lounsburyi* on 28 May 1976 (84 days after HK-1 release) at the release site.

		Non-Parasitized		Parasitized^z					
				HK-1 on 3rd instar CSS				*Aspidiotiphagus* In	
						Pupa			
Plant Organ	Total No. Females CSS Examined	Non-Gravid %	Gravid %	Egg %	Larva %	Live %	Dead %	2nd instar CSS %	3rd instar CSS %
leaves	703	22.62	7.54	0.28	1.00	0.57	4.84	58.46	4.55
twigs	973	48.30	45.94	0	0.40	0	0.20	4.11	1.03

z HK-1 = *Aphytis lingnanensis* Hong Kong 1.

Table 20. Summary of wind direction and speed in the Orlando area from January to June 1976.

Item	January	February	March	April	May	June
Resultant Direction	S.E.	S.E.	N.W.	S.W.	N.W.	S.W.
Resultant Speed km/h	5.15	1.45	3.22	4.35	4.35	4.67
Average Speed km/h	14.32	14.65	14.00	13.68	14.81	11.75

Source: U.S. Department of Commerce. Local climatological data, Orlando Jetport at McCoy, Nat. Oceanic Atmospheric Admin. (1976).

CHAPTER VI

GENERAL CONCLUSIONS CONCERNING CITRUS SNOW SCALE POPULATION DYNAMICS

In Florida, climatic conditions are rarely severe enough to completely prevent citrus snow scale (Unaspis citri (Comstock), Homoptera: Diaspididae) reproduction throughout the year. Scales are found on every aerial organ of sweet orange trees except the ephemeral flowers. During the peak rainfall period, from late spring to fall (May-June through September-October) scale colonies remain intact in well protected areas on trunk, limbs, and twigs. They may also be found on leaves, in a network of small branches, twigs, and leaves, if the tree has a huge protective canopy.

The population curve representing all stages of the citrus snow scale on citrus trunks followed a seasonal pattern: a period of population increase was observed from fall (September-December 1975) through winter (December-March) and on into spring (March-June 1976) followed by a period of population decline from spring through summer (June-September), and on into fall and winter of 1976-77. There were slight variations in these trends, for crawlers, males, and females. Crawler and male scale populations peaked in April, while female scales reached a maximum density in July. All scale stages showed low population levels in January 1977, but in January 1976 only females reached the seasonal minimum during that month. In October 1975, both crawlers and males declined to a low population level. Thus, it seems possible that natural factors responsible for regulating citrus snow scale populations have differential effects on both sexes and the different developmental stages.

On leaves and twigs female citrus snow scale population generally followed the same trend observed in females on trunks; however, on both leaves and twigs, there was a secondary peak in the female population in November. This suggests that female citrus snow scale population dynamics are distinctly influenced by the different plant organs on which the scale may occur.

Citrus snow scale densities, including all considered stages, increased with tree age on both trunks and leaves. The scale density was also influenced by plant varieties. The effect of plant variety could also be detected from scale counts taken from each of the different plant organs. On the trunk the overall population was highest on 'Parson Brown', intermediate on 'Valencia', and lowest on 'Pineapple'. On leaves, 'Parson Brown' had a higher female scale density on leaves than on either 'Valencia' or 'Pineapple'; these latter two did not differ significantly in female scale counts.

The results have shown the different effects of various factors on particular citrus snow scale stages or on the whole scale population. These results suggest that not only different evaluation methods but also, scale stages, plant organs, and other factors (economic, ecologic, etc.) must be combined to get a more realistic understanding of the citrus snow scale status on Florida citrus.

Aspidiotiphagus parasitism on leaves, followed the female scale population trends but it did not show a secondary peak in numbers during November. On twigs Aspidiotiphagus parasitism was very low and relatively stable during the year.

Rainfall apparently plays an important role in the fluctuations of scale seasonal populations. The onset of daily rainfall in late spring (June) coincides with the population decline period. Regular scale counts on infested trees and studies of specific colonies in exposed and protected areas on tree limbs suggest that the mechanical washing effect of rainfall and associated runoff contribute to the decline in scale numbers, especially of crawlers and males. The excessive moisture also facilitates growth of microorganisms, some of which may be saprophytic or pathogenic to citrus snow scale.

There are well protected areas on trees, which are seldom soaked by the rainfall, where neither microorganisms nor algae develop. These surviving-scale population areas act as an insect reservoir for re-infestation of the tree.

Since female citrus snow scale population fluctuations were similar on leaves and twigs, any of these plant organs could be used to monitor female scale populations (crawlers and male citrus snow scale were monitored only on citrus trunks). However, as the percent of scales parasitized by Aspidiotiphagus lounsburyi (Berlese and Paoli) (Hymenoptera: Aphelinidae) on leaves was different from the percent parasitization of scales on twigs, it seems advisable to sample both leaves and twigs in order to evaluate parasite activity on citrus snow scale.

The survey on male snow scales showed some effects of tree locations in the field on scale infestation. Edaphic factors (e.g. nutritional conditions, microbial activity, organic matter, soil depth, water level fluctuation, and aeration, etc.) may be involved on these responses, either directly (affecting the insect itself) or indirectly (affecting the plant host).

To evaluate the susceptibility of different sweet orange varieties to citrus snow scale, it is advisable to use a 10-class rating system rather than a 5-class system as it was used on this survey. However, an additional improvement would be a check on live scale density during the insect's increasing population phase.

Younger trees harbored fewer citrus snow scales than older trees. While this might be due to shorter time of exposure, the younger trees also offer less shelter for scales, not only from the standpoint of physical space, but also in terms of quality of protection against rainfall runoff and other physical environmental factors.

The Hong-Kong 1 (HK-1) stock of Aphytis lingnanensis Compere (Hymenoptera: Aphelinidae) released at Paradise Island against the citrus snow scale could not be established at this location. However, based on initial post release recoveries, releases made during early winter to early spring should offer the highest probability of success. Reasons for success and failure of efforts to colonize the HK-1 strain at different localities and times should be investigated.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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